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A Statistical Analysis of Metal and Nonmetal Mine Fire Incidents in the United States From 1950 to 1984

By Shail J. Butani and William H. Pomroy

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

h	hour	pct	percent
min	minute	yr	year

A Statistical Analysis of Metal and Nonmetal Mine Fire Incidents in the United States From 1950 to 1984

By Shail J. Butani[1] and William H. Pomroy[2]

ABSTRACT

This Bureau of Mines publication presents a statistical analysis of official U.S. Mine Safety and Health Administration (MSHA) metal and nonmetal mine fire reports from 1950 through 1984, plus accounts of selected nonreportable fires (less than 30 min and no injury) and opinion data on fire hazards from mine safety directors. Fires were analyzed by time trends, ore type, ignition source, burning substance, location in mine, equipment involved, means of detection, duration, number of injuries and fatalities, mining method, and successful extinguishing agent.

The leading ignition sources were electricity in underground fires and engine heat in reported surface fires. The most frequent burning substance was combustible liquids for all nonreportable fires, reported surface fires, and reported underground fires from 1978 to 1984. For underground fires reported prior to 1978, timber was the leading burning substance. Mobile equipment was the type most frequently involved in both underground and surface fires. Underground fires occurred most often in haulageway or drift areas, and reported surface fires occurred most often in plant and mill buildings, while most nonreportable surface fires occurred in other areas. The most common methods of extinguishment were water hose lines for reported fires and dry chemical hand-portable extinguishers for nonreportable fires.

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INTRODUCTION

In support of the Bureau of Mines research on mine fire protection, two separate baseline studies on mine fire incidents have been prepared. The first study addressed coal mine fires. The results of that study are summarized in the Bureau's Information Circular 8830, "A Statistical Analysis of Coal Mine Fire Incidents in the United States From 1950 to 1977." This second report, addressing metal and nonmetal mine fires, is the companion to IC 8830. Together, these two reports provide a comprehensive, factual summary of the mining industry's fire experience.

This report, like IC 8830, covers (1) MSHA fire incident reports, (2) records of nonreportable fires (less than 30 min and no injury), and (3) mine safety directors' opinions on fire hazards. The MSHA fire reports provide the most reliable, objective, and accurate historcial record of the major noncoal mine fires that occurred during the study period (1950 through 1984). However, MSHA fire reports alone understate the true magnitude of the fire problem because metal and nonmetal mines have been legally required to report fires to MSHA only since 1968. Although some fires were reported prior to 1968, doubtless a great many were not. Also, the reporting regulations that took effect in 1968 specify that only fires lasting 30 min or longer or involving an injury need to be reported. MSHA fire reports are thus limited in scope by MSHA's legal authority. In order to provide a more comprehensive data base, it was also necessary to gather and analyze mine company records of nonreportable fires.

Finally, since mine fires are relatively rare events, it is desirable to analyze not only the fires themselves, but also the "near-misses" (which occur much more frequently) and the unsafe conditions that could give rise to future fires. Thus, opinion data from mine safety directors were collected and separately analyzed in an effort to broaden the discussion and to characterize and rank mine fire hazards in general. The 1950 to 1977 data were collected via a research and development contract with Allen Corp. of America. These data have been previously published in the form of a Bureau Open File Report and are available from the National Technical Information Service (NTIS).[3] The 1978 through 1984 data have not been previously published. The reported mine fire data have also been formatted and entered into a computer data base using the Lotus 1-2-3 software[4] for IBM-compatible personal computers. Use of this computer data base would greatly simplify the analysis of metal and nonmetal mine fires for the specialized purposes of individual users. Microdata are also available from the authors on hard copy.

DATA ANALYSIS METHODS

Three statistical techniques were employed to analyze the data collected: the chi-square test, the t-test, and the Spearman rank order correlation. A detailed discussion of these methods can be found in basic statistical books.[5] Additionally, incidence rates were computed where possible. Each of these methods of analysis is discussed below.

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[3]Baker, R. M., J. Nagy, L. B. McDonald, and J. Wishmyer. An Annotated Bibliography of Metal and Nonmetal Mine Fire Reports (contract J0295035, Allen Corp. of America). Volume I. BuMines OFR 68(1)-81, 1980, 64 pp.; NTIS PB 81-223729. Volume II. BuMines OFR 68(2)-81, 1980, 284 pp.; NTIS PB 81-223737. Appendix. BuMines OFR 68(3)-81, 1980, 390 pp.; NTIS PB 81-223745.

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

[5]Mendenhall, W. Introduction to Statistics. Wadsworth Publ. Co., Inc., 1965, 305 pp.

Siegel, S. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill, 1956, 312 pp.

CHI-SQUARE

Chi-square (χ^2), as an analysis technique, is used in situations requiring comparison of an observed number of responses in each of certain chosen categories with an expected number, which is based on the null hypothesis (see discussion of null hypothesis below). The observed values or frequencies are those obtained by direct observation or by tabulation of the various types of data. The expected or theoretical frequencies are generated on the basis of some underlying assumption (the null hypothesis), independent of the observed data. The computational formula for chi-square values is

$$\chi^2 = \sum_{i=1}^{K} \frac{(O_i - E_i)^2}{E_i},$$

where K = number of categories,

O_i = observed number of cases in i^{th} category,

E_i = expected number of cases in i^{th} category under the null hypothesis,

and $\sum_{i=1}^{K}$ directs one to sum over all categories.

That is, chi-square equals the summation of the squared value of the difference of observed and expected values divided by the corresponding expected value.

If the agreement between the observed and expected frequencies is close, the differences $(O_i - E_i)$ will be small, and consequently, chi-square will be small. On the other hand, if the differences are large, the value of chi-square will also be large. The larger chi-square is, the more likely it is that the observed values did not come from the population on which the null hypothesis is based. If the computed value of chi-square is greater than the tabled value of chi-square for a specified significance level (α; usually $\alpha = 0.05$ or 0.01) with $K - 1$ degrees of freedom (d.f.), then the difference is said to be significant. Thus, the null hypothesis concerning the theoretical frequencies is rejected; that is, the differences between the observed and expected frequencies are greater than would be expected to exist by chance.

Throughout this report, the null hypothesis used for analyzing data within a time period is that an equal number of fires are expected for all categories within each factor studied--ore type, ignition source, location, etc. As an example, refer to the tabulation below, which shows reported underground fires by ignition source, 1968-77:[6]

	Number	Pct
Electrical................	39	46.4
Welding sparks or hot slag	16	19.0
Engine heat...............	7	8.3
Spontaneous combustion....	13	15.5
Friction..................	6	7.1
Explosives................	1	1.2
Other.....................	2	2.4
Total.................	84	100.0

According to the above-stated hypothesis, all types of ignition sources would be expected to have caused an equal or nearly equal number of fires. Thus, <u>the expected frequency for each ignition source type would be the average frequency of all ignition source types specified</u>. In this case, the expected value is

$$\frac{39 + 16 + 7 + 13 + 6 + 1 + 2}{K = 7} = 12.0,$$

where K = number of different types of ignition sources.

Thus, the computation of chi-square is as follows:

$$\chi^2 = \frac{(39 - 12.0)^2}{12} + \frac{(16 - 12.0)^2}{12} + \ldots + \frac{(2 - 12.0)^2}{12} = 85.67.$$

[6]Data from table 7, which appears later in this report.

The tabled value of chi-square with 6 (K - 1) d.f. at $\alpha = 0.01$ is 16.81. Since the computed value of chi-square (85.67) is greater than the tabled value of chi-square (16.81), the null hypothesis is rejected. This implies that all ignition source types are not equally involved in metal and nonmetal underground fires for the period 1968-77.

When the expected frequencies are small (less than five), the chi-square test is generally not valid. Also, the chi-square test is not appropriate for the actual number of fires across time periods, because the reporting requirements before 1968 were less stringent and, consequently, a number of fires were not reported pre-1968. Hence, the underlying assumption of an equal number of fires per year is not met. Therefore, the chi-square test is not applied across all situations; instead, the t-test, concerning proportions (probabilities), is used.

t-TEST

The first type of t-test is for the one-sample case; it is concerned with determining whether the proportion of observed fires in a category within a time period is more than what is expected under the null hypothesis (that all categories have the same proportion of fires). Only probabilities that are greater than what is expected are analyzed, because the concern is for those categories that are hazardous. The computational formula for the t-test is

$$t = \frac{p - p_o}{\sqrt{\frac{p_o(1 - p_o)}{n}}},$$

where p = observed proportion of accidents falling in the category of interest,

p_o = proportion of accidents expected under the null hypothesis (in this report, p_o = 1.00 divided by the number of categories),

and n = total number of specified fires within a time period.

A comparison is made between the calculated value of t and the tabled value of t; the tabled value of t with its associated d.f. (n - 1) is such that the area under the distribution curve to the right of t_α is equal to α, the significance level. If the calculated value of t is greater than the tabled value of t, the difference is said to be significant and not merely due to chance. Consequently, the null hypothesis is rejected in favor of the alternative hypothesis; namely, the category has proportionately more fires than what is expected. As an example, refer to the tabulation below, which shows reported underground electrical fires by location, 1950-67:[7]

	Number	Pct
Haulageway-drift..........	7	31.8
Substation-shop-storage-pump....................	4	18.2
Shaft-raise-winze.........	7	31.8
Working face..............	2	9.1
Mined-out waste...........	1	4.5
Other.....................	1	4.5
Total.................	22	100.0

The null hypothesis is tested, that the probability of electrical fires in haulageway-drift locations is equal to 0.167 (1.00 divided by the number of categories).

$$t = \frac{p - p_o}{\sqrt{\frac{p_o(1 - p_o)}{n}}}$$

$$= \frac{0.318 - 0.167}{\sqrt{\frac{0.167\ (0.833)}{22}}}$$

$$= 1.91.$$

The tabled value of t with 21 d.f. at the 0.05 significance level is 1.72. Since the computed value is greater than

[7]Data from table 10, which appears later in this report.

the tabled value, the null hypothesis is rejected; that is, the relative frequency of the haulageway-drift location as the site of electrical fires is significantly more than its share of one out of every six fires.

The absolute t-values ($|t|$) for the one-sample case, where applicable, are shown at the bottom of the tables, under the appropriate time periods.

The second type of t-test concerns the difference between two proportions. This test determines whether the observed difference between proportions from the two samples is a real difference or is due to random variation. The null hypothesis in this test is $P_1 = P_2$, where P_1, and P_2 are the proportion of cases in population 1 and population 2, respectively, possessing a certain attribute that is of interest. The computational formula for this test is

$$t = \frac{p_1 - p_2}{\sqrt{p(1 - p)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}},$$

where p_1 = number of cases in sample 1 possessing a certain attribute, divided by n_1,

p_2 = number of cases in sample 2 possessing a certain attribute, divided by n_2,

n_1 = sample size drawn from population 1,

n_2 = sample size drawn from population 2,

and $$p = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2}.$$

A comparison is then made between the absolute calculated value of t and the tabled value of t. As before, the tabled value of t with its associated d.f. ($n_1 + n_2 - 2$) is such that the area under the distribution curve to the right of t_α is equal to α, the significance level. The absolute value of t is compared to the tabled value because the alternative hypothesis is that either P_1 is greater than P_2 or P_2 is greater than P_1. Again, if the absolute calculated value of t is greater than the tabled value of t, then the difference between the two proportions is significant and not merely due to chance. Consequently, the null hypothesis that the two probabilities are equal is rejected in favor of one probability being greater than the other.

The following data can be used to test the hypothesis that the proportion of underground electrical fires located in haulageway-drift locations in 1950 to 1967 is equal to the proportion in 1968 to 1977. Reported underground electrical fires by location, two time periods:[8]

	Period I 1950-67		Period II 1968-77	
	No.	Pct	No.	Pct
Haulageway-drift.	7	31.8	18	46.2
Substation-shop-storage-pump....	4	18.2	13	33.3
Shaft-raise-winze	7	31.8	3	7.7
Working face.....	2	9.1	4	10.3
Mined-out waste..	1	4.5	0	.0
Other............	1	4.5	1	2.6
Total.........	22	100.0	39	100.0

$$t = \frac{p_1 - p_2}{\sqrt{p(1 - p)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}},$$

where $p_1 = \frac{7}{22} = 0.318$,

$p_2 = \frac{18}{39} = 0.462$,

$n_1 = 22$,

$n_2 = 39$,

and $$p = \frac{22\ (0.318) + 39\ (0.462)}{22 + 39}$$

$$= 0.410.$$

[8]Data from table 10.

$$t = \frac{0.318 - 0.461}{\sqrt{(0.410)\ (0.590)\left(\frac{1}{22} + \frac{1}{39}\right)}};$$

$$|t| = 1.09.$$

The absolute calculated value of t = 1.09 is less than the tabled value of t = 1.645 (with 59 d.f. and $\alpha = 0.05$), so the null hypothesis cannot be rejected. That is, the difference between the two proportions could be due to random variation.

The absolute t-values for the two-sample case, where applicable, are given in the last two columns of the tables.

SPEARMAN RANK ORDER CORRELATION

The Spearman rank order correlation (r_s) is a measure of concordance or agreement, the tendency of two ranks to be similar. This test was chosen as the measure of correlation because it is nonparametric--it makes no assumption about the shape of the distribution curve of the underlying population. It was also chosen because both variables can be measured in at least an ordinal scale so that the objects or individuals under study may be ranked in two ordered series. For example, using the data in table 1, the number of fires, denoted as $X_1, X_2, \ldots X_N$, and the year, denoted as $Y_1, Y_2, \ldots Y_N$, may be ranked as shown in table 2. Rank correlation may then be used to determine the relation between the X's and Y's. The formula used in calculating the Spearman rank order correlation is as follows:

$$r_s = 1 - \frac{6 \sum^{N} d_i^2}{N(N^2 - 1)},$$

where $d_i = X_i - Y_i$

and N = total number of observations.

The value of r_s is always equal to or greater than -1.0 and equal to or less than 1.0; that is, $-1.0 \leq r_s \leq 1.0$. If the computed value of r_s exceeds the tabled value based on N and α (significance level), then the rank order correlation is said to be significant; that is, the agreement between the two sets of ranks is greater than would be expected to occur by chance.

Using the ranked tabulated data in table 2 as an example, the Spearman rank order correlation would be

$$r_s = 1 - 6\,\frac{[(3 - 1)^2 + (18.5 - 2)^2 + \ldots + (23.0 - 34)^2 + (20.5 - 35)^2]}{35\ [(35)^2 - 1]} = 0.569$$

For N = 35 and $\alpha = 0.01$, the tabled value of r_s is 0.432. Since the computed value of r_s is greater than the tabled value, the rank order correlation is said to be significant.

TABLE 1. - Reported underground fire incidents by year

Year	Number of incidents	Year	Number of incidents	Year	Number of incidents
1950....	1	1962....	0	1974....	15
1951....	5	1963....	2	1975....	10
1952....	3	1964....	4	1976....	8
1953....	3	1965....	2	1977....	13
1954....	2	1966....	2	1978....	23
1955....	4	1967....	2	1979....	10
1956....	6	1968....	4	1980....	7
1957....	10	1969....	0	1981....	11
1958....	2	1970....	4	1982....	12
1959....	7	1971....	5	1983....	7
1960....	3	1972....	12	1984....	6
1961....	3	1973....	21	Total.	229

TABLE 2. - Ranking of reported underground fire incidents by year

Year	Number of incidents	Rank: Year	Rank: Incidents	Year	Number of incidents	Rank: Year	Rank: Incidents
1950....	1	1	3.0	1968....	4	19	15.5
1951....	5	2	18.5	1969....	0	20	1.5
1952....	3	3	11.5	1970....	4	21	15.5
1943....	3	4	11.5	1971....	5	22	18.5
1954....	2	5	6.5	1972....	12	23	30.5
1955....	4	6	15.5	1973....	21	24	34.0
1956....	6	7	20.5	1974....	15	25	33.0
1957....	10	8	27.0	1975....	10	26	27.0
1958....	2	9	6.5	1976....	8	27	25.0
1959....	7	10	23.0	1977....	13	28	32.0
1960....	3	11	11.5	1978....	23	29	35.0
1961....	3	12	11.5	1979....	10	30	27.0
1962....	0	13	1.5	1980....	7	31	23.0
1963....	2	14	6.5	1981....	11	32	29.0
1964....	4	15	15.5	1982....	12	33	30.5
1965....	2	16	6.5	1983....	7	34	23.0
1966....	2	17	6.5	1984....	6	35	20.5
1967....	2	18	6.5	Total.	229	NAp	NAp

NAp Not applicable. $r_s = 0.569^{**}$ (significant at 1-pct level).

LEVELS OF SIGNIFICANCE AND ROUNDING

Levels of significance are provided in the tables for all statistical analyses reported. Significant results are identified by either one or two asterisks, denoting probabilities of 0.05 and 0.01, respectively. Lack of an asterisk indicates that the results were not significant; that is, there is a greater than 0.05 probability that the results could have occurred by chance. In some cases, no test was made, for any one of several reasons. These cases are denoted as "not determined" (ND).

The sum of the percentage components in the tables may not exactly equal 100.0 because of rounding.

INCIDENCE RATE

The last type of analysis is concerned with the relative measure based on incidence rates (IR). Incidence rates are used to standardize or normalize the number of fires on the basis of exposure hours so that meaningful comparisons can be made. The incidence rates in this report represent the number of fires per 10,000 full-time workers and are calculated as

$$IR = \frac{\text{number of fires}}{\text{total hours worked}} \times 20 \text{ million h},$$

where 20 million h is equivalent to 10,000 full-time workers working 40 h per week and 50 weeks per year.

Data from 1980[9] may be used as an example. The incidence rate for 1980 is

$$IR_{80} = \frac{7}{54{,}200{,}000} \times 20{,}000{,}000;$$

$$IR_{80} = 2.6.$$

REPORTED FIRES

For the period 1950-77, MSHA fire reports were acquired through searches of the official files of all MSHA metal-nonmetal inspection offices and the headquarters office at Arlington, VA. The inspection offices included in the search are listed in the appendix.

[9]Data from table 4, which appears later in the report.

At each MSHA office, project personnel searched through all accident report files on fires, explosives, and ignitions. Only reports on fires were utilized, but other reports were reviewed in order to locate any incorrectly filed or titled reports. In the review process, the fire reports that were considered to be minor burn accidents were eliminated. For the period 1977-84, MSHA's Health and Safety Analysis Center (HSAC) computer data base of mine accidents was searched. Several fire reports not contained in HSAC's files were also provided by MSHA's Denver Mining Technology Center, Ventilation Branch.

MSHA fire reports were analyzed under two headings: underground fires and surface fires at underground and surface mines.

UNDERGROUND FIRES

Time Trends

The first analysis determines time trend effects on the number of fires in each year. Table 1 lists 229 fire incidents in underground mines by year of occurrence. The Spearman rank order correlation, based on table 2, between years and number of fires is 0.569, compared with the tabled value of 0.432 at the $\alpha = 0.01$ level. This indicates the rank order correlation is significant; that is, on the average, the number of fires reported has increased with time. This can be seen in figure 1, which shows there were a higher number of fires for which a report could be located for the period beginning in 1972.

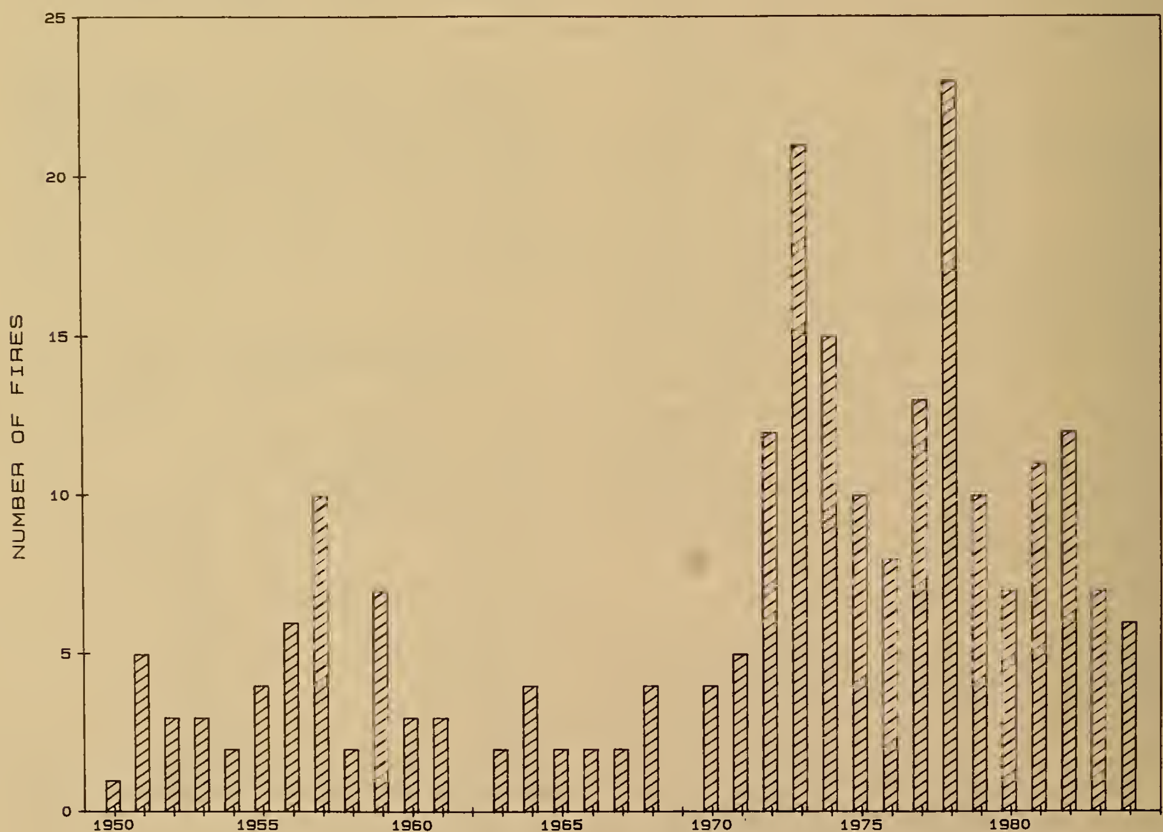

Figure 1.—Underground fire incidents by year, 1950-84.

The analysis is geared toward a breakdown by three time periods of mine law: pre-1967 Metal and Nonmetal Act, post-1967 Metal and Nonmetal Act, and post-1977 Mine Health and Safety Act. Table 3 displays the numbers of fire incidents by the three time periods. The chi-square for this table is computed on the assumption of an equal number of fires each year. This highly significant value indicates that differences exist in the frequency of occurrence of reported fires during the three time periods. This could be because prior to 1968 record-keeping was not required for accidents (including fires) that occurred in metal and nonmetal mines. Although the Bureau was the designated authority over metal and nonmetal mining, investigative reporting of accidents was not undertaken on a regular basis, and no specific agency was charged with this activity. Usually the technical relationship of the mine operator with the nearest Bureau representative or the seriousness of the occurrence were factors determining whether or not a fire incident was reported.

Based on discussions with personnel from each of the MSHA offices visited during this project, it is also apparent that a significant percentage of reports of fire incidents for this period (pre-1968) have been misplaced over the years of shift and reorganization of personnel and offices in the Bureau, the Mine and Environmental Safety Association (MESA), and MSHA. If the conservative assumption is made that all fire incidents occurring after passage of the Metal and Nonmetal Mining Act of 1967 have been located, a simple calculation using average fires per year shows that possibly 65 pct of all fires that occurred before passage of the act have not been accounted for. As will be shown later in this report, there has been a dramatic reduction in the average duration of fires reported following passage of the act and an increase in reporting of fire incidents, mandated by the creation of MESA and, ultimately, MSHA. This supports the hypothesis that proportionately more fires less than 24 h in length went unreported during the early years under consideration. If, on the other hand, the assumption of an average yearly fire incidence is in error, the fire hazardousness of the underground mining environment must be examined.

TABLE 3. - Number of reported underground fire incidents by three time periods

Period	Observed	Expected	Average per year
I: 1950-67....	61	118	3.4
II: 1968-77...	92	65	9.2
III: 1978-84..	76	46	10.9
Total or av.	229	229	6.5

$\chi^2 = 58.32^{**}$ (significant at 1-pct level).

Over the years following the mid-1960's, underground metal and nonmetal mining equiment has developed an increased dependency on diesel power and electricity as prime movers. This could represent a significant source of increase in fire hazard. Furthermore, the growth of the industry during the 1970's in size of operations and number of miners employed also represents an overall potential increase in the underground fire hazard.

Significantly then, the trend seen in figures 1 and 2 is either toward increased awareness (via reporting) of fires in underground metal and nonmetal mines or toward increased hazardousness of the environment.

To fully explain the fire hazard by year, the analysis should be based on relative measures such as incident rates, that is, the number of fires occurring per 20 million h worked, the equivalent of 10,000 full-time workers per year. (See "Data Analysis Methods.") This type of analysis was performed for the period 1978-84, since this was the most current period and the only period for which the hours could be easily obtained from MSHA's data base (table 4). The expected number of incidents for each year is computed on the assumption that the number of fires would be in proportion to the relative exposure (for example, for 1980

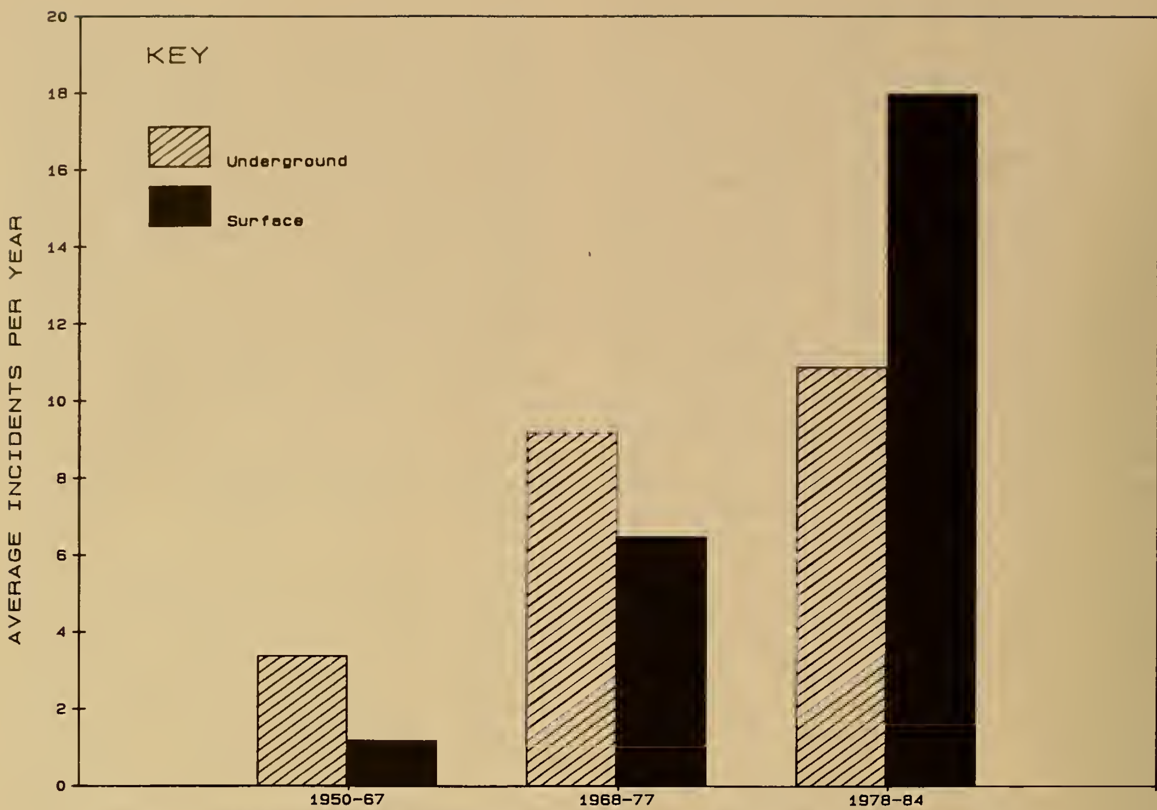

Figure 2.—Average number of fire incidents per year, underground versus surface, during three time periods.

TABLE 4. - Reported underground fire incidence rates, 1978-84

Year	Observed number of incidents	Hours worked, 10^3 h	Incidence rate[1]	Expected number of incidents
1978.........	23	51,900	8.9	13
1979.........	10	55,000	3.6	14
1980.........	7	54,200	2.6	13
1981.........	11	54,500	4.0	13
1982.........	12	37,700	6.4	9
1983.........	7	27,050	5.2	7
1984.........	6	27,400	4.4	7
Total or IR	76	307,750	4.9	76

$\chi^2 = 13.05^*$ (significant at 5-pct level).
[1]Per 20 million h worked.

it would be (54,200/307,750) × 76). The chi-square value computed from the observed and expected number of fires indicates that not all years were equally hazardous. This fact can be easily seen from figure 3, which also shows that there is no apparent time trend on incidence rates for this period.

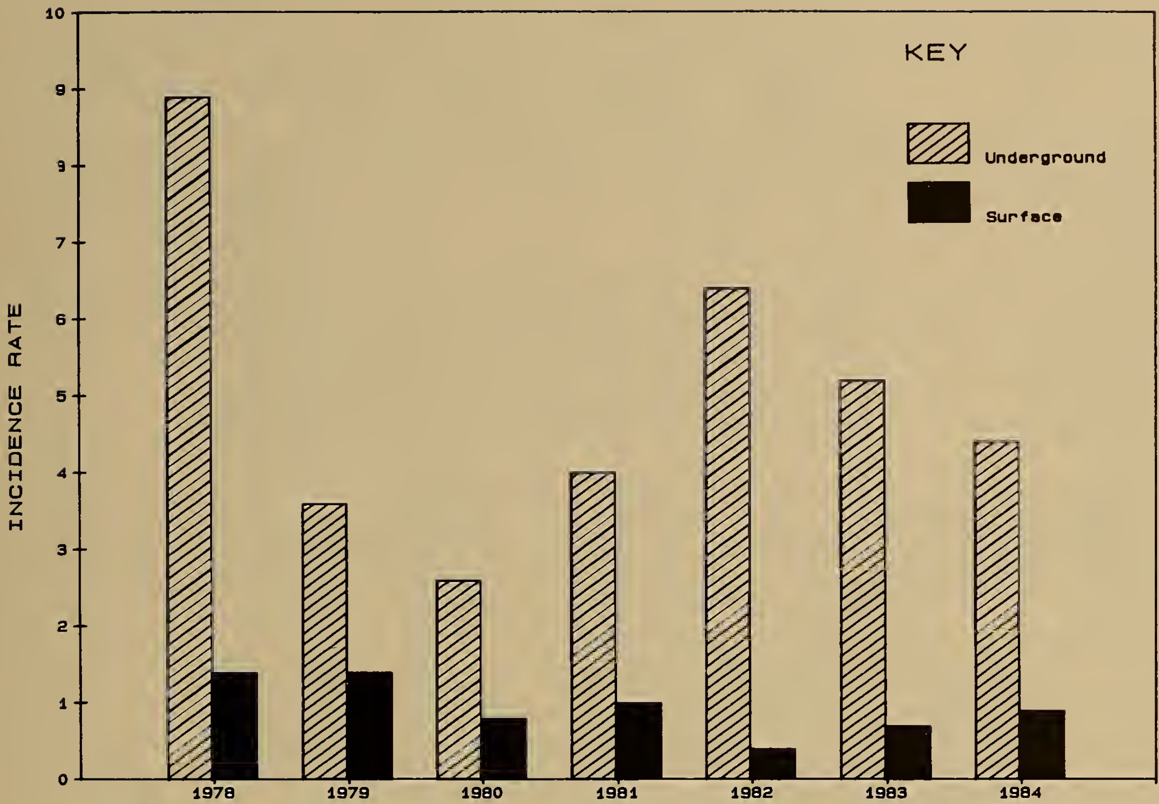

Figure 3.—Fire incidence rates (based on 20 million h worked), by year, underground versus surface, 1978-84.

Ore Type

Table 5 shows underground fires by ore type for the three time periods. Analysis within any given time period indicates that the differences among different ore types are highly significant; all three overall chi-square values are significant at the 0.01 level. The most noticeable comparison is between ore types iron and salt in the period 1950-67. These data also show that the distribution of fires by ore type has changed from period to period.

According to the t-values, the relative frequency of copper fires decreased from 1968-77 to 1978-84, lead-zinc fires increased from 1950-67 to 1968-77, iron fires decreased from 1950-67 to 1968-77 and again from 1968-77 to 1978-84, and salt fires increased from 1950-67 to 1968-77.

Since an estimate of the hours worked in each ore type was readily available from MSHA's data base for the period 1978-84, a detailed analysis by ore type for this period was performed (table 6). The relative measure of rate is based on the number of fire incidences per 20 million h worked, which is equivalent to 10,000 full-time workers per year. (See "Data Analysis Methods.") The expected number of fires for each type of ore mined was computed on the assumption that all mines were equally hazardous. Hence, the expected number of fires for each ore mined would be in proportion to the relative exposure (for example, for salt it would be (15,400/307,750) × 76). Since the chi-square value of 26.55 is highly significant, it means all ore types were not equally hazardous. The relative measure of incidence rates as depicted in

TABLE 5. - Reported underground fires by principal ore, three time periods

Ore	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Copper	10	17.5	21	23.6	9	11.8	40	18.0	0.87	1.95*
Lead-zinc	4	7.0	15	16.9	18	23.7	37	16.7	1.72*	1.09
Iron	25	43.9	8	9.0	1	1.3	34	15.3	4.91**	2.17*
Salt	0	.0	11	12.4	12	15.8	23	10.4	2.76**	ND
Silver	3	5.3	9	10.1	6	7.9	18	8.1	1.04	ND
Other	15	26.3	25	28.1	30	39.5	70	31.5	ND	ND
Total specified	57	100.0	89	100.0	76	100.0	222	100.0		
Specified	57	93.4	89	96.7	76	100.0	222	96.9		
Unspecified	4	6.6	3	3.3	0	.0	7	3.1		
Total	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2:										
Specified	45.63**		15.97**		41.32**					
Without "Other"	47.29**		8.81		17.70**					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 6. - Average reported underground fire incidence rates by ore, 1978-84

Ore	Observed number of incidents	Hours worked, 10^3 h	Incidence rate[1]	Expected number of incidents
Salt	12	15,400	15.6	4
Lead-zinc	18	44,050	8.2	11
Silver	6	15,850	7.6	4
Copper	9	48.650	3.7	12
Other[2]	31	183,800	3.4	45
Total or IR	76	307,750	5.0	76

χ^2 = 26.55** (significant at 1 pct level).
[1]Per 20 million h worked.
[2]Includes iron (1 incident).

figure 4 shows salt to be the most hazardous of all ore types, followed by lead-zinc and silver.

Ignition Source

Table 7 shows fires by ignition source for the three time periods. The overall chi-square values indicate that the different ignition source totals are significantly different for each of the three time periods. The overwhelming ignition source for all the time periods was electrical. The distribution of specified fires among the seven ignition source types was very similar for the first two time periods but changed for the third period. One such category is "Spontaneous combustion," where the proportion of fires was significantly down from 15.5 pct in 1968-77 to 1.4 pct in 1978-84. According to the t-test values, the proportion of electrical fires was also significantly down between 1968-77 and 1978-84, but the proportion of engine heat fires had increased for the same time period. With electrical fires removed, the differences among the remaining ignition sources are significant at the 1-pct level for the periods 1968-77 and 1978-84, but are not significant for the 1950-67 period.

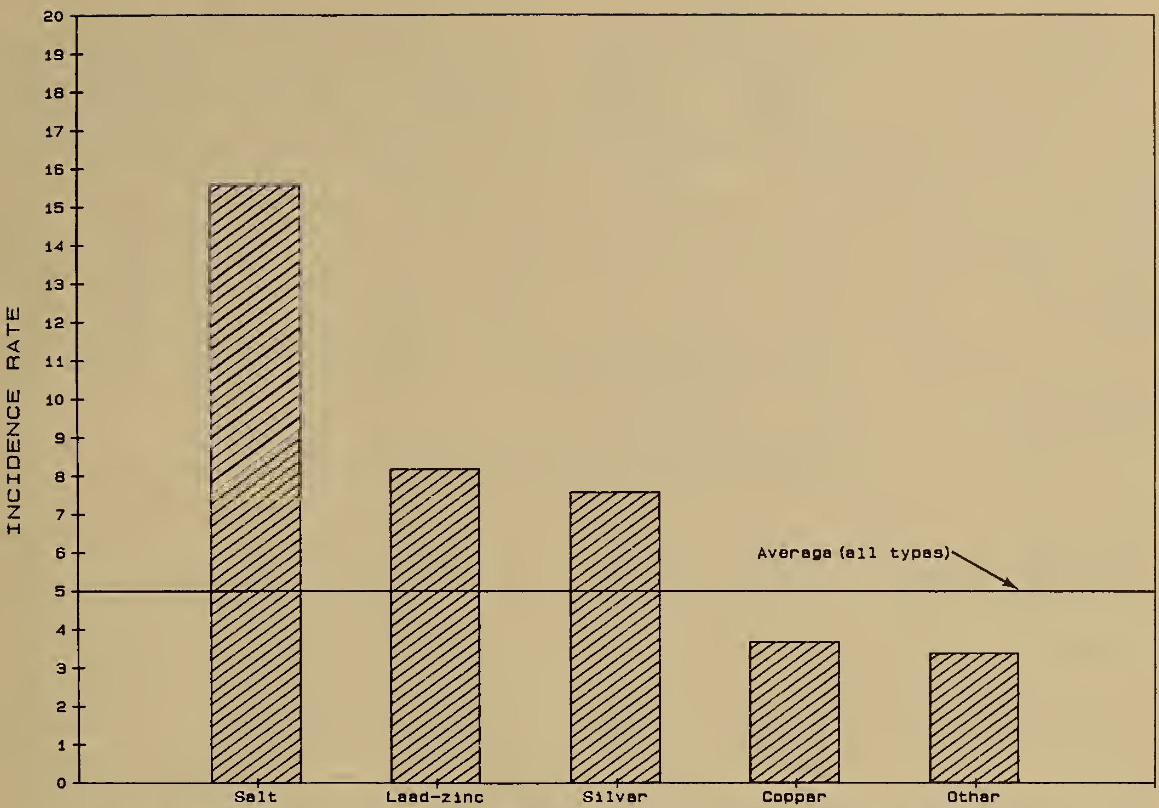

Figure 4.—Average underground fire incidence rates (based on 20 million h worked), by ore type, 1978-84.

Since 1970, there has been some effort by persons in the Bureau and MSHA to ban smoking in underground metal and nonmetal mines. Smoking is, at present, banned in certain areas of a mine, such as fueling areas. There have been about a half-dozen reported underground mine fires directly attributed to smoking during the study period. These fires involved the ignition of mine timbers and lasted longer than 24 h, but resulted in no injuries or fatalities. In fires where the cause was unspecified, smoking was identified as a possible or probable cause in at least four cases.

A survey of MSHA district managers revealed a cross section of opinions relating to the hazardousness of smoking in underground metal and nonmetal mines. However, most acknowledged that smoking materials, where evident of a fire's cause, would be the first substance to be consumed by the fire and, thus, might be involved in more fires than is generally known.

Burning Substance

Table 8 shows underground fires by burning substance for the three time periods. One of the underlying assumptions in utilizing either the chi-square test or the t-test is that of independence. This means among other things that any given observation falls into and only one category. In the case of fires categorized by burning substances, it would mean that each fire is classified into

TABLE 7. - Reported underground fires by ignition source, three time periods

Ignition source	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Electrical............	22	42.3	39	46.4	21	29.6	82	39.6	ND	2.15*
Welding sparks or hot slag.................	10	19.2	16	19.0	7	9.9	33	15.9	ND	1.60
Engine heat...........	2	3.8	7	8.3	18	25.4	27	13.0	1.02	2.87**
Spontaneous combustion	8	15.4	13	15.5	1	1.4	22	10.6	ND	3.05**
Friction..............	3	5.8	6	7.1	9	12.7	18	8.7	ND	1.16
Explosives............	3	5.8	1	1.2	2	2.8	6	2.9	ND	ND
Other.................	4	7.7	2	2.4	13	18.3	19	9.2	ND	ND
Total specified....	52	100.0	84	100.0	71	100.0	207	100.0		
Specified.............	52	85.2	84	91.3	71	93.4	207	90.4		
Unspecified...........	9	14.8	8	8.7	5	6.6	22	9.6		
Total..............	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2:										
Specified...........	40.35**		85.67**		122.61**					
Without electrical.	10.40		23.67**		20.10**					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 8. - Reported underground fires by burning substance,[1] three time periods

Burning substance	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Timber................	48	57.1	40	29.9	19	21.8	107	35.1	4.00**	1.32
Combustible liquids...	6	7.1	21	15.7	31	35.6	58	19.0	1.86*	3.42**
Insulation............	9	10.7	29	21.6	16	18.4	54	17.7	2.07*	ND
Rubber................	3	3.6	18	13.4	9	10.3	30	9.8	2.40**	ND
Other.................	18	21.4	26	19.4	12	13.8	56	18.4	ND	ND
Total specified....	84	100.0	134	100.0	87	100.0	305	100.0		
Specified.............	84	96.6	134	99.3	87	96.7	7	97.8		
Unspecified...........	3	3.4	1	.7	3	3.3	312	2.2		
Total..............	87	100.0	135	100.0	90	100.0		100.0		
χ^2:										
Specified..........	79.93**		10.85*		16.62**					
Without timber....	14.00**		3.11		16.82**					

ND Not determined. **Significant at 1-pct level.
*Significant at 5-pct level. [1]In many fires, more than 1 substance was burning.

only one burning substance type. The data on fires by burning substances, of course, violates this assumption. However, in analyzing the data of this table, it was found that fire in one burning substance type was independent of fires in other burning substance types. If this assumption is true, then the results of the analysis given below are valid for the intended purpose. The large chi-square values for each of the three time periods indicate that the differences among the different burning substance are significant. These data show that timber was the most frequent substance burning, while wiring insulation and combustible liquids were also frequently involved in fires, especially since 1968.

The t-test values indicate that the distribution of fires by burning substance has changed from one period to

another. There was a significant decrease in the proportion of fires attributed to timer from 1950-67 to 1968-77 and 1978-84. It should be noted, however, that the decrease was not significant between the second and third time periods. The fires due to combustible liquids, on the other hand, have increased from one period to the next. There was a definite shift from timber as the most frequent burning substance to combustible liquids, insulation, and rubber between 1950-67 and 1968-77.

Location

The locations of fires in underground metal and nonmetal mines appear in table 9. The large chi-square values for the three time periods indicate that significant differences exist in the frequency of fires occurring at various locations. Fires occurred predominantly in haulageway-drift entry areas for the periods 1968-77 and 1978-84; for the period 1950-67, they occurred in shaft-raise-winze areas. This result also means there was a change in the distribution of fire location from one period to another. The number of fires occurring in mined-out wastes and shaft-raise-winze areas declined while those in haulageway-drift areas increased. To determine the sources of fires at the various locations, the data on the two most common sources were analyzed separately.

Table 10 shows electrical fires by location for the three time periods. Since there are too many categories for the number of observations, the expected frequencies are small (less than five). Hence, the chi-square test is not valid for this situation. The data in this table and in table 11, therefore, were analyzed by the t-test. The t-values for all three time periods indicate that the relative frequency of electrical fires along haulageway-drift areas, where literally miles of cable are installed, was more than what would be expected by chance. Electrical fires in the moving equipment, such as load-haul-dumps, occurred frequently here. The t-values also show the relatively high frequencies of electrical fires at substation-shop-storage-pump areas for the 1968-77 period and at shaft-raise-winze areas for the 1950-67 period to be significant. In comparing the distribution of fires across time periods, the t-test revealed <u>no</u> significant difference in the proportion of fires between 1950-67 and

TABLE 9. - Reported underground fires by location, three time periods

Location	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Haulageway-drift......	12	19.7	42	46.2	42	59.2	96	43.0	3.34**	1.64*
Shaft-raise-winze.....	20	32.8	11	12.1	9	12.7	40	17.9	3.10**	ND
Mined-out waste.......	13	21.3	10	11.0	2	2.8	25	11.2	1.74*	1.97*
Working face..........	5	8.2	9	9.9	6	8.5	20	9.0	ND	ND
Substation-shop-storage-pump.........	8	13.1	16	17.6	6	8.5	30	13.5	ND	ND
Other.................	3	4.9	3	3.3	6	8.5	12	5.4	ND	ND
Total specified....	61	100.0	91	100.0	71	100.0	223	100.0		
Specified............	61	100.0	91	98.9	71	93.4	223	97.4		
Unspecified..........	0	.0	1	1.1	5	6.6	6	2.6		
Total.............	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2:										
Specified.........	18.77**		61.11**		94.38**					
Without haulageway-drift.....	19.06**		6.41		4.28					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 10. - Reported underground electrical fires by location, three time periods

Location	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Haulageway-drift......	7	31.8	18	46.2	11	55.0	36	44.4	1.09	0.64
Substation-shop-storage-pump.........	4	18.2	13	33.3	3	15.0	20	24.7	1.27	1.50
Shaft-shaft-winze.....	7	31.8	3	7.7	2	10.0	12	14.8	2.44**	ND
Working face..........	2	9.1	4	10.3	0	.0	6	7.4	ND	ND
Mined-out waste.......	1	4.5	0	.0	1	5.0	2	2.5	ND	ND
Other.................	1	4.5	1	2.6	3	15.0	5	6.2	ND	ND
Total specified....	22	100.0	39	100.0	20	100.0	81	100.0		
Specified.............	22	100.0	39	100.0	20	95.2	81	98.8		
Unspecified...........	0	.0	0	.0	1	4.8	1	1.2		
Total..............	22	100.0	39	100.0	21	100.0	82	100.0		
|t|:										
Haulageway-drift...	1.91*		4.94**		4.60**					
Substation-shop-storage-pump......	0.19		2.79**		ND					
Shaft-raise-winze..	1.91*		ND		ND					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 11. - Reported underground welding or cutting fires by location, three time periods

Location	1950-67		1968-77		1978-84		Total	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct
Shaft-raise-winze.....	6	60.0	6	37.5	3	42.9	15	45.5
Haulageway-drift......	2	20.0	7	43.8	2	28.6	11	33.3
Substation-shop-storage-pump.........	2	20.0	0	.0	2	28.6	4	12.1
Mined-out waste.......	0	.0	1	6.3	0	.0	1	3.0
Working face..........	0	.0	0	.0	0	.0	0	.0
Other.................	0	.0	2	12.5	0	.0	2	6.1
Total..............	10	100.0	16	100.0	7	100.0	33	100.0

|t|:
Shaft-raise-winze.................................... 4.44**
Haulageway-drift..................................... 2.57**

**Significant at 1-pct level.

1968-77, and between 1968-77 and 1978-84 for the haulageway-drift entry areas and substation-shop-storage-pump areas. The same analysis for the shaft-raise-winze area, on the other hand, showed a significant decline in the proportion of fires from 1950-67 to 1968-77.

Table 11 contains the analysis for welding-cutting fires by location for two of the time periods. Owing to the small sample size in each period, which leads to large fluctuations, the total number of fires was analyzed so that statistically meaningful conclusions could be drawn from these data. The t-tests for a one-sample case showed that fires from welding or cutting operations occurred more frequently in the mine shaft-raise-winze and in haulageway-drift areas than in other areas of the mine.

Equipment Involved

Table 12 categorizes fires by equipment involved, for the three time periods. During the tabulation of these data, it became obvious that some changes in the reporting mechanism have occurred over time for the "Unspecified," "None," and "Unknown" categories. The data for these categories, therefore, are such that it is not possible to obtain a separate fire count for each category. It should be noted that the combination of the three categories comprises a major portion of all the fires by equipment type. Where equipment is specified, the chi-square values for the last two time periods are significant, which indicates that some equipment types were more involved in fires than others. The most prone pieces of equipment were either mobile, such as load-haul-dumps, or electrical (that is, stationary electrical equipment). Two t-tests were performed for the mobile and electrical equipment. The first compared the 1950-67 and 1968-77 periods; the second compared the 1968-77 and 1978-84 periods. All of the t-values were not significant.

To fully explain the relative fire hazard of the various types of equipment used in underground mines, fire incidents should be normalized based on actual exposure hours or the number of equipment pieces. Although some data to support such an analysis were located, it was found that the data available were inadequate to normalize the equipment most frequently associated with underground fires. The authors believe that estimates of equipment populations beyond the scope of presently available data would lead to highly questionable results; therefore, no attempt was made to compute incidence rates by equipment for underground fires at this time.

An analysis of the leading ignition source of fires where equipment is involved is presented in table 13. As in table 12, the equipment category "Unspecified-unknown-none" comprises a major portion of all the electrical fires. Also, as explained before, the small number of fires precludes the use of the chi-square test for this table. The t-tests show that the relative frequency of electrical equipment in electrical ignition fires was much higher than the expected (0.25) for all time periods. The same type of analysis also shows that the relative frequency of mobile equipment was significantly more than expected for the period 1968-77.

TABLE 12. - Reported underground fires by equipment involved, three time periods

Equipment	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Mobile	6	26.1	24	46.2	31	59.6	61	48.0	1.64	1.38
Electrical	10	43.5	16	30.8	9	17.3	35	27.6	1.07	1.61
Conveyor	1	4.3	5	9.6	6	11.5	12	9.4	ND	ND
Other	6	26.1	7	13.5	6	11.5	19	15.0	ND	ND
Total specified	23	100.0	52	100.0	52	100.0	127	100.0		
Specified	23	37.7	52	56.5	52	68.4	127	55.5		
Unspecified-unknown-none[1]	38	62.3	40	43.5	24	31.6	102	45.5		
Total	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2: Specified	7.09		17.69**		33.69**					

ND Not determined.

**Significant at 1-pct level.

[1]The reporting mechanism did not permit the classification of fires into 3 separate categories.

TABLE 13. - Reported underground electrical fires by equipment, three time periods

Equipment	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Electrical............	6	54.5	12	42.9	8	47.1	26	46.4	0.66	ND
Mobile................	4	36.4	15	53.6	7	41.2	26	46.4	.97	ND
Conveyor..............	0	.0	0	.0	1	5.9	1	1.8	ND	ND
Other.................	1	9.1	1	3.6	1	5.9	3	5.4	ND	ND
Total specified....	11	100.0	28	100.0	17	100.0	56	100.0		
Specified.............	11	50.0	28	71.8	17	81.0	56	68.3		
Unspecified-unknown-none................	11	50.0	11	28.2	4	19.0	26	31.7		
Total..............	22	100.0	39	100.0	21	100.0	82	100.0		
|t|:										
Electrical.........	2.26^{*}		2.19^{*}		2.10^{*}					
Mobile............	.87		3.49^{**}		1.54					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 14. - Reported underground fires by means of detection, three time periods

Means of detection	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Operator-worker (immediate)..........	9	16.7	28	31.5	29	43.9	66	31.6	1.96^{*}	1.59
Workers (not immediate)...........	20	37.0	23	25.8	21	31.8	64	30.6	1.42	.82
Incoming shift........	3	5.6	10	11.2	7	10.6	20	9.6	1.15	ND
Shift boss-foreman....	8	14.8	6	6.7	6	9.1	20	9.6	1.57	ND
Welding crew..........	7	13.0	8	9.0	0	.0	15	7.2	ND	ND
Other.................	7	13.0	14	15.7	3	4.5	24	11.5	ND	ND
Total specified....	54	100.0	89	100.0	66	100.0	209	100.0		
Specified.............	54	88.5	89	96.7	66	86.8	209	91.3		
Unspecified...........	7	11.5	3	3.3	10	13.2	20	8.7		
Total..............	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2: Specified........	18.44^{**}		26.21^{**}		59.09^{**}					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

Means of Detection

The person(s) discovering a fire are listed in table 14. The large chi-square values for each of the three time periods indicate that the frequencies for the six different categories are statistically different. The most frequent detection of fire occurs immediately or after a short period of time by workers in the area. Most metal and nonmetal mine fire reports do not identify the specific job title of the person discovering a fire.

The t-test shows there was a significant increase in the relative frequency of the category "Operator-worker (immediate)" between the periods 1950-67 and 1968-77. The same type of analysis, however, shows the changes to be nonsignificant for the next three categories.

Duration

Duration of fires appears in table 15. Note that for the periods 1950-67 and 1978-84, the duration is not specified

TABLE 15. - Reported underground fires by duration, three time periods

Duration, h	I 1950-67		II 1968-77		III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
0 to 0.5	5	11.9	11	13.1	8	14.0	24	13.1	ND	ND
0.5 to 1	2	4.8	5	6.0	6	10.5	13	7.1	ND	ND
1+ to 4	4	9.5	31	36.9	21	36.8	56	30.6	3.23**	ND
4+ to 24	8	19.0	20	23.8	8	14.0	36	19.7	ND	1.43
24+	23	54.8	17	20.2	14	24.6	54	29.5	3.92**	ND
Total specified	42	100.0	84	100.0	57	100.0	183	100.0		
Specified	42	68.9	84	91.3	57	75.0	183	79.9		
Unspecified	19	31.1	8	8.7	19	25.0	46	20.1		
Total	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2: Specified	33.95**		22.90**		13.26*					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

for an estimated 30 and 25 pct, respectively, of all the reported fires. It should also be noted that many of the fires lasting less than 1/2 h were not reportable based on duration. Most of these were reportable because of an associated injury; some were reported as a courtesy; and others were investigated by MSHA inspectors after hearing about the fire from a third party. As a general rule, reports of these fires were found at MSHA subdistrict offices in the form of internal memos or letter reports.

Of those fires that were reported and where the duration is specified, the chi-square values are significant for all the periods. This means the number of fires are not evenly distributed across the five duration categories. In the 1950-67 time period, the most frequent duration was 24 h or more. The t-test value between the 1950-67 and 1968-77 periods indicates there was definitely a decline in the relative frequency of fires for this category. Based on these results and on discussions with the concerned officials, it can be concluded that prior to 1968 fires lasting 24 h or longer were more frequently reported than others.

Further analysis of ignition sources by duration was performed for two time periods, 1968-77 and 1978-84, and the results are presented in table 16. It should be noted that for period 1978-84, the data on duration of fires are less than complete. In about 25 pct of the reports, the duration of the fire was unspecified. Of the specified durations in both time periods, all the spontaneous combustion fires lasted 24 h or longer, and about 50 pct of the electrical ignition fires lasted 1 to 4 h.

Number of Injuries

Fire injuries for the three time periods appear in table 17. In all the time periods, the fires where no injuries occurred comprise an overwhelming proportion of all the fires. Once the fires with no injuries are eliminated, the sample size for each of the time periods becomes too small to draw any statistically meaningful conclusions. A cross-tabulation of injury fires by ignition source appears in table 18. As shown, the source of most injury fires was electrical, followed by welding and engine heat. Prior to 1978, there were no injuries involved with fires occurring from engine heat. Yet, during the 1978-84 time period, engine heat was the largest source of all injury fires. Cross-tabulations of injury fires by location and equipment appear in tables 19 and 20. Injury fires occurred predominantly along haulageway-drifts, followed by working face areas. Prior to 1968, it appears that more injury fires started at the shaft or in a mined-out area. Since 1968, they seem to have occurred more in haulageway-drifts and working face areas.

TABLE 16. - Reported underground fires by ignition source and duration, two time periods

Ignition source	0 to 0.5 h		0.5 to 1.0 h		1+ to 4 h		4+ to 24 h	
	1968-77	1978-84	1968-77	1978-84	1968-77	1978-84	1968-77	1978-84
Electrical..........	5	0	3	3	19	11	9	1
Welding sparks or hot slag...........	4	1	2	0	3	0	3	1
Engine heat.........	1	3	0	2	2	3	2	3
Spontaneous combustion.........	0	0	0	0	0	0	0	0
Friction............	1	1	0	0	3	3	0	0
Explosives..........	0	1	0	1	0	0	1	0
Other...............	0	2	0	0	2	3	0	3
Unspecified.........	0	0	0	0	2	1	5	0
Total............	11	8	5	6	31	21	20	8

Ignition source	24+ h		Unspecified		Total	
	1968-77	1978-84	1968-77	1978-84	1968-77	1978-84
Electrical..........	1	2	2	4	39	21
Welding sparks or hot slag...........	2	3	2	2	16	7
Engine heat.........	1	2	1	5	7	18
Spontaneous combustion.........	12	1	1	0	13	1
Friction............	1	2	1	3	6	9
Explosives..........	0	0	0	0	1	2
Other...............	0	3	0	2	2	13
Unspecified.........	0	1	1	3	8	5
Total............	17	14	8	19	92	76

TABLE 17. - Reported underground fires by number of injuries, three time periods

Number of injuries	1950-67		1968-77		1978-84		Total	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct
0....................	54	88.5	85	92.4	63	82.9	202	88.2
1....................	4	6.6	3	3.3	11	14.5	18	7.9
2 to 5..............	2	3.3	3	3.3	2	2.6	7	3.1
6 to 10.............	1	1.6	1	1.1	0	.0	2	.9
10+.................	0	.0	0	.0	0	.0	0	.0
Total............	61	100.0	92	100.0	76	100.0	229	100.0

TABLE 18. - Reported underground injury fires by ignition source, three time periods

Ignition source	1950-67	1968-77	1978-84	Total
Electrical................	2	4	3	9
Welding sparks or hot slag	2	1	2	5
Engine heat...............	0	0	5	5
Spontaneous combustion....	2	2	0	4
Friction..................	1	0	1	2
Other.....................	0	0	2	2
Total..................	7	7	13	27

The type of equipment most involved in injury fires was mobile-type equipment. In fact, in the 1978-84 period, all of the injury fires with a known equipment type involved mobile equipment.

Number of Deaths

Table 21 lists fires by number of deaths. The only significant result is the overall reporting frequency of nonfatal fires. Once the nonfatal fires are removed, the sample sizes in each of the three periods become too small to draw any statistically meaningful conclusions.

Mining Method

Table 22 shows fires by mining method for the three time periods. For a large portion of the fire reports, mining method was not specified for the 1950-67 and 1978-84 periods. The chi-square values for all time periods indicate significant differences among the fire frequencies associated with the five specified mining methods. The t-test values show the fire incidences occurred with a higher than expected relative frequency in the caving method for the period 1950-67 and in the room-and-pillar method for the periods 1968-77 and 1978-84. The t-values show that the relative frequency of fires increased from one period to the next for the room-and-pillar method and decreased for the caving method. These results indicate that the distribution of the fire incidents for the mining methods has changed from period to period. For the open stoping method, however, the change

TABLE 19. - Reported underground injury fires by location, three time periods

Location	1950-67	1968-77	1978-84	Total
Haulageway-drift................	1	3	6	10
Working face....................	1	3	2	6
Shaft-raise-winze...............	3	0	0	3
Substation-shop-storage-pump....	0	1	2	3
Mined-out area..................	2	0	0	2
Other...........................	0	0	2	2
Unspecified.....................	0	0	1	1
Total........................	7	7	13	27

TABLE 20. - Reported underground injury fires by equipment, three time periods

Equipment	1950-67	1968-77	1978-84	Total
Mobile..........................	1	2	11	14
Electrical......................	2	1	0	3
Other...........................	1	0	0	1
Unspecified-unknown-none........	3	4	2	9
Total........................	7	7	13	27

TABLE 21. - Reported underground fires by number of deaths, three time periods

Number of deaths	1950-67		1968-77		1978-84		Total	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct
0.....................	57	93.4	86	93.5	76	100.0	219	95.6
1.....................	2	3.3	2	2.2	0	.0	4	1.7
2 to 5................	0	.0	2	2.2	0	.0	2	.9
6+....................	2	3.3	2	2.2	0	.0	4	1.7
Total.............	61	100.0	92	100.0	76	100.0	229	100.0

TABLE 22. - Reported underground fires by mining method, three time periods

Mining method	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Room-and-pillar.......	10	19.6	31	36.0	34	57.6	75	38.3	2.03*	2.57**
Caving................	21	41.2	18	20.9	5	8.5	44	22.4	2.54**	2.02**
Open stoping..........	13	25.5	16	18.6	5	8.5	34	17.3	1.02	1.70*
Cut-and-fill..........	1	2.0	14	16.3	10	16.9	25	12.8	2.59**	ND
Other.................	6	11.8	7	8.1	5	8.5	18	9.2	ND	ND
Total specified....	51	100.0	86	100.0	59	100.0	196	100.0		
Specified.............	51	83.6	86	93.5	59	77.6	196	85.6		
Unspecified...........	10	16.4	6	6.5	17	22.4	33	14.4		
Total.............	61	100.0	92	100.0	76	100.0	229	100.0		
χ^2: Specified........	22.23**		17.84**		53.80**					
$\|t\|$:										
Room and pillar....	ND		3.72**		7.23**					
Caving.............	3.78**		ND		ND					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 23. - Reported underground fires by successful extinguishing agent,[1] three time periods

Extinguishing agent	1950-67		1968-77		1978-84		Total	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct
Water..................	26	38.2	43	35.2	20	39.2	89	36.9
Dry chemical...........	5	7.4	27	22.1	16	31.4	48	19.9
Burned out.............	9	13.2	18	14.8	7	13.7	34	14.1
Sealing................	18	26.5	10	8.2	3	5.9	31	12.9
Other..................	10	14.7	24	19.7	5	9.8	39	16.2
Total specified....	68	100.0	122	100.0	51	100.0	241	100.0
Specified..............	68	95.8	122	97.6	51	60.0	241	85.8
Unspecified............	3	4.2	3	2.4	34	40.0	40	14.2
Total[1].............	71	100.0	125	100.0	85	100.0	281	100.0
Total fires........	61	NAp	92	NAp	76	NAp	229	NAp

NAp Not applicable.
[1]More than one successful extinguishing agent was used in some fires.

is significant only from 1968-77 to 1978-84. The relative frequency of the cut-and-fill also increased from 1950-67 to 1968-77.

To better explain the relative fire hazard of the various types of mining methods, it would be more appropriate to relate the fires to the average number of mines associated with each mining method and time period. As no reliable data on the average number of mines by mining methods were available, this type of analysis was not performed.

Successful Extinguishing Agent

Tables 23 and 24 delineate fires by successful extinguishing agent for the three time periods. Table 23 gives the frequency with which an extinguishing agent was successfully used. The fires in which two agents were successfully used were entered under both categories in this table. Table 24 gives the bivariate distribution of the fires, showing which extinguishing agents were used together. Note that in 1978-84, the

TABLE 24. - Reported underground fires, joint distribution of successful extinguishing agents, by three time periods

	Water			Dry chemical			Burned out			Sealing			Other			Unspecified		
Period[1]........	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Water..........	18	19	14	3	13	3	0	2	0	4	0	1	1	9	2			
Dry chemical...				1	8	10	0	4	2	1	0	0	1	2	1			
Burned out.....							9	10	5	0	0	0	0	2	0			
Sealing........										13	9	2	0	1	0			
Other..........													7	10	2			
Unspecified....																3	3	34

[1]I: 1955-67; II: 1968-77; III: 1978-84.

TABLE 25. - Reported surface fire incidents by year

Year	Number of incidents	Year	Number of incidents	Year	Number of incidents
1950....	1	1962....	4	1974....	10
1951....	0	1963....	3	1975....	5
1952....	0	1964....	2	1976....	12
1953....	1	1965....	0	1977....	13
1954....	0	1966....	0	1978....	29
1955....	0	1967....	1	1979....	31
1956....	3	1968....	4	1980....	16
1957....	1	1969....	4	1981....	21
1958....	1	1970....	4	1982[1]...	5
1959....	1	1971....	2	1983....	10
1960....	0	1972....	6	1984....	14
1961....	3	1973....	5	Total	212

[1]Statistics for 1982 in surface mining of stone, clay, colloidal phosphate, and sand and gravel are based on July through December only. These operations were excluded from MSHA jurisdiction by House Joint Resolution 370, December 15, 1981. On July 15, 1982, the Congress approved House Resolution 6685, which restored MSHA's jurisdiction to all operations except those of States or political subdivisions.

successful extinguishing agent was not specified in about 45 pct (34/76) of the fire reports. Where the extinguishing agents were specified, it was found that none of the standard statistical tests were applicable, as the basic assumption of independence was violated. That is, water and dry chemicals were used more frequently than other agents in fires involving two agents. Hence, the following conclusions are based on simple examination of the data: (1) in 1968-77, the frequency with which two successful extinguishing agents were used is much higher than in the other two periods, (2) water was the predominant agent in all three periods, (3) there was a definite shift from sealing to dry chemical, and (4) the relative frequency of "Burned out" was approximately the same throughout the three periods.

SURFACE FIRES AT SURFACE AND UNDERGROUND MINES

Time Trends

As with underground fires, the first analysis looked at the time trends. Table 25 lists 212 fire incidents by year for surface fires. The number of fires for 1982 is based only on July through

December for stone, clay, colloidal phosphate, and sand and gravel, because these operations were excluded from MSHA's jurisdiction from January through June of that year.

It can be seen from table 25 and figure 5 that there were a higher number of fires for which a report could be located for the period beginning in 1972. This fact is further confirmed by the Spearman rank order correlation test based on table 26. The highly significant r_s value of 0.855 indicates that, on the average, the number of fires reported increased with time.

Table 27 displays the number of fire incidents by three time periods. The chi-square for this table is computed on the assumption of an equal number of fires for each year. This highly significant value indicates, as shown in figure 2, that differences exist in the frequency with which surface fires were reported during the three time periods. As with underground fires, this could be because prior to 1968 there was no recordkeeping requirement for accidents (including fires) that occurred in metal and nonmetal mines. Also, a significant percentage of reports of fire incidents during this period (pre-1968) have been misplaced over the years of shift and reorganization of personnel and offices in the Bureau and MSHA.

Significantly then, the trend as seen in figures 2 and 5 is either toward increased awareness (via reporting) of fires in surface metal and nonmetal mines or toward an increasingly hazardous environment, or both.

Table 28 gives the surface incidence rates for the period 1978-84. These

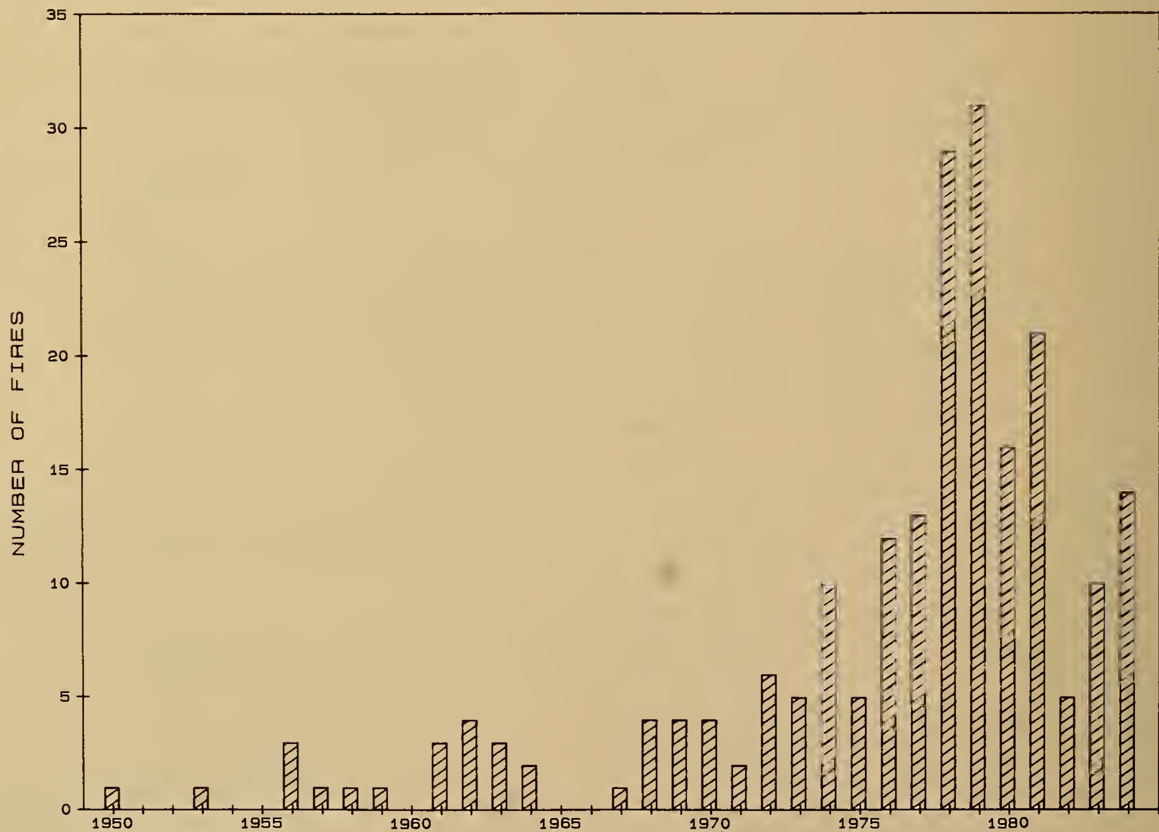

Figure 5.—Surface fire incidents by year, 1950-84.

TABLE 26. - Ranking of reported surface fire incidents by year

Year	Number of incidents	Rank: Year	Rank: Incidents	Year	Number of incidents	Rank: Year	Rank: Incidents
1950.........	1	1	10.5	1968.........	4	19	20.5
1951.........	0	2	4.0	1969.........	4	20	20.5
1952.........	0	3	4.0	1970.........	4	21	20.5
1953.........	1	4	10.5	1971.........	2	22	14.5
1954.........	0	5	4.0	1972.........	6	23	26.0
1955.........	0	6	4.0	1973.........	5	24	24.0
1956.........	3	7	17.0	1974.........	10	25	27.5
1957.........	1	8	10.5	1975.........	5	26	24.0
1958.........	1	9	10.5	1976.........	12	27	29.0
1959.........	1	10	10.5	1977.........	13	28	30.0
1960.........	0	11	4.0	1978.........	29	29	34.0
1961.........	3	12	17.0	1979.........	31	30	35.0
1962.........	4	13	20.5	1980.........	16	31	32.0
1963.........	3	14	17.0	1981.........	21	32	33.0
1964.........	2	15	14.5	1982[1]........	5	33	24.0
1965.........	0	16	4.0	1983.........	10	34	27.5
1966.........	0	17	4.0	1984.........	14	35	31.0
1967.........	1	18	10.5	Total......	212	NAp	NAp

NAp Not applicable. $r_s = 0.855^{**}$ (significant at 1-pct level).

[1]Statistics for 1982 in surface mining of stone, clay, colloidal phosphate, and sand and gravel are based on July through December only. These operations were excluded from MSHA jurisdiction by House Joint Resolution 370, December 15, 1981. On July 15, 1982, the Congress approved House Resolution 6685, which restored MSHA's jurisdiction to all operations except those of States or political subdivisions.

TABLE 27. - Number of surface fire incidents by three time periods

Period	Observed	Expected	Average per year	Period	Observed	Expected	Average per year
I: 1950-67....	21	109	1.2	III: 1978-84..	126	42	18.0
II: 1968-77...	65	61	6.5	Total or av..	212	212	6.1

χ^2: 239.31^{**} (significant at 1-pct level).

TABLE 28. - Reported surface fire incidence rates, 1978-84

Year	Observed number of incidents	Hours worked, 10^3 h	Incidence rate[1]	Expected number of incidents
1978.........	29	418,650	1.4	21
1979.........	31	440,200	1.4	22
1980.........	16	417,100	.8	21
1981.........	21	400,350	1.0	20
1982.........	5	221,550	.4	11
1983.........	10	289,150	.7	15
1984.........	14	299,450	.9	15
Total or IR	126	2,486,450	1.0	126

$\chi^2 = 13.16^*$ (significant at 5-pct level).

[1]Per 20 million h worked.

incidence rates are equivalent to the number of fires per 10,000 full-time workers (See "Data Analysis Methods.") The chi-square values computed from the observed and expected number of fires indicate that not all years were equally hazardous. Figure 3 shows years 1978 and 1979 to have the highest incidence rate.

Ore Type

Table 29 shows surface fires by ore type for the three time periods. Fires occurred most often at surface limestone and iron mines, especially for the period 1978-84. The chi-square test for the period 1968-77 indicates that the differences in ore totals, after the "Other" category is eliminated are not significant. This test was not performed for the period 1950-67 because 11 fires among 4 different categories yield an expected frequency of less than 3 fires per category. An examination of the data for this period shows that the frequency of fires was the highest in iron ore. According to the t-values, the only significant change in the relative frequency was in iron ore between 1950-67 and 1968-77.

A detailed analysis by ore type was also performed for the most current period, 1978-84 (table 30). The chi-square value of 12.71 is significant at the 5-pct level, indicating that all ore types were not equally hazardous. The relative measure of incidence rates as depicted in figure 6 shows iron to be the most hazardous and sand and gravel to be the least hazardous.

TABLE 29. - Reported surface fires by principal ore, three time periods

Ore	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Crushed limestone.....	1	5.6	9	16.4	24	19.4	34	17.3	1.16	0.48
Iron..................	7	38.9	5	9.1	18	14.5	30	15.2	2.96**	1.00
Copper................	3	16.7	5	9.1	9	7.3	17	8.6	.89	.42
Sand and gravel.......	0	.0	5	9.1	9	7.3	14	7.1	1.33	.42
Other.................	7	38.9	31	56.4	64	51.6	102	51.8	ND	ND
Total specified....	18	100.0	55	100.0	124	100.0	197	100.0		
Specified.............	18	85.7	55	84.6	124	98.4	197	92.9		
Unspecified...........	3	14.3	10	15.4	2	1.6	15	7.1		
Total..............	21	100.0	65	100.0	126	100.0	212	100.0		
χ^2: Specified without "Other"..............	ND		2.00		10.80*					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 30. - Average reported surface fire incidence rates by ore, 1978-84

Ore	Observed number of incidents	Hours worked, 10^3 h	Incidence rate[1]	Expected number of incidents
Iron.............	18	198,350	1.8	10
Crushed limestone	24	458,400	1.0	23
Copper...........	9	236,850	.8	12
Sand and gravel..	9	362,400	.5	19
Other[2]...........	66	1,230,450	1.1	62
Total or IR....	26	2,486,450	1.0	126

χ^2 = 12.71* (significant at 5-pct level).
[1]Per 20 million h worked.
[2]Includes 2 incidents in unspecified ores.

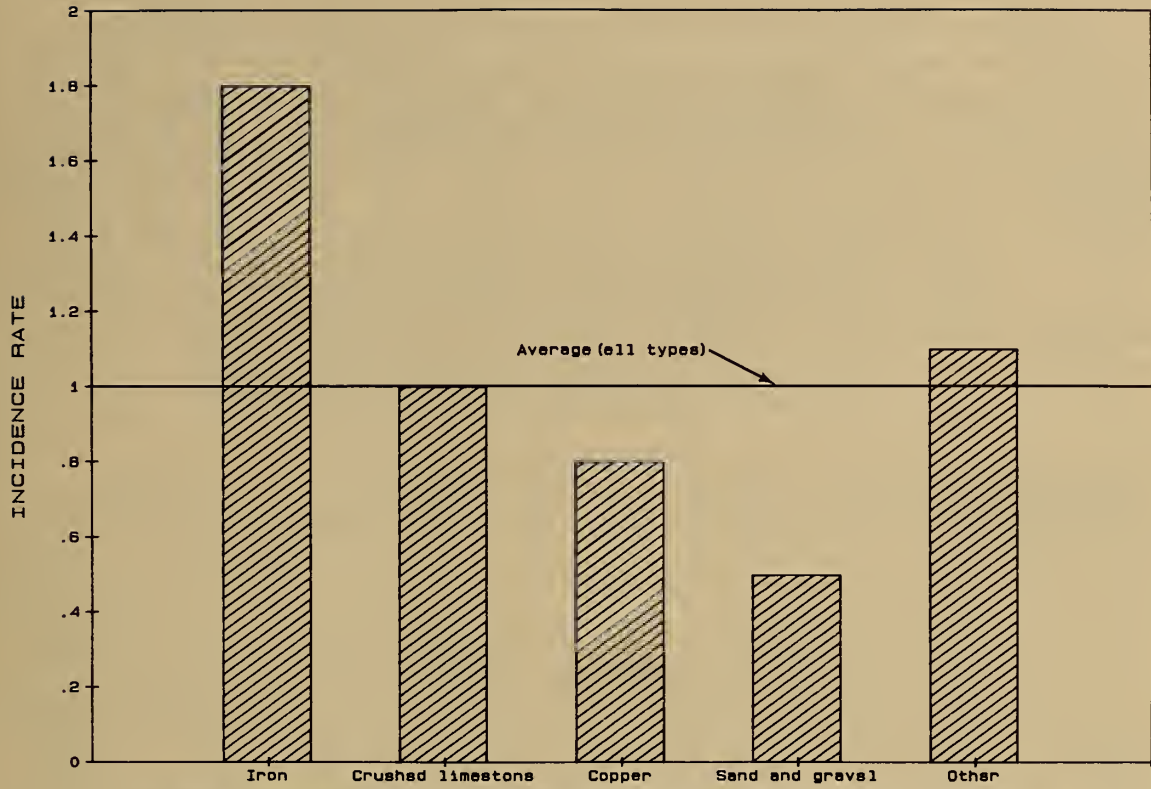

Figure 6.—Average surface fire incidence rates (based on 20 million h worked), by ore type, 1978-84.

Ignition Source

Table 31 shows fires by ignition source for the three time periods. The number of unspecified fires comprises a major portion of the total fires, especially for the 1978-84 period, thus raising some questions on the completeness of the data. The chi-square values with and without the "Other" category indicate that the different ignition source totals are significantly different for the time periods 1968-77 and 1978-84. No chi-square test was performed for the first period as there were too few observations. It is apparent, however, that the leading ignition source for this period was electrical. The t-tests also show that the proportion of engine heat fires increased from 1968-77 to 1978-84 while the proportion of electrical fires declined over the same time.

Burning Substance

The data on surface fires by burning substance for the three time periods are shown in table 32. In analyzing the data of this table, the same basic assumption was made on independence of burning substances as outlined for its counterpart table 8 on underground fires. The chi-square test shows that the differences in the frequency with which the various substances were involved in fires were significant for the periods 1968-77 and 1978-84 but not for the period 1950-67. The relative frequency of combustible

TABLE 31. - Reported surface fires by ignition source, three time periods

Ignition source	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Engine heat...........	1	5.3	9	16.1	38	37.3	48	27.1	1.20	2.79**
Electrical............	6	31.6	15	26.8	16	15.7	37	20.9	.40	1.68*
Welding...............	3	15.8	11	19.6	22	21.6	36	20.3	.37	ND
Friction..............	1	5.3	1	1.8	8	7.8	10	5.6	ND	ND
Other.................	8	42.1	20	35.7	18	17.6	46	26.0	ND	ND
Total specified....	19	100.0	56	100.0	102	100.0	177	100.0		
Specified.............	19	90.5	56	86.2	102	81.0	177	83.5		
Unspecified...........	2	9.5	9	13.8	24	19.0	35	16.5		
Total..............	21	100.0	65	100.0	126	100.0	212	100.0		
χ^2:										
Specified..........	ND		17.93**		24.08**					
Without other.....	ND		11.56**		23.05**					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

TABLE 32. - Reported surface fires by burning substance,[1] three time periods

Burning substance	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Combustible liquids...	4	11.1	24	28.2	70	55.6	98	39.7	2.04*	3.92**
Construction material.	5	13.9	19	22.4	25	19.8	49	19.8	1.07	ND
Insulation............	5	13.9	11	12.9	8	6.3	24	9.7	ND	1.64
Rubber................	4	11.1	9	10.6	11	8.7	24	9.7	ND	ND
Timber................	11	30.6	6	7.1	3	2.4	20	8.1	3.40**	1.65*
Other.................	7	19.4	16	18.8	9	7.1	32	13.0	ND	ND
Total specified....	36	100.0	85	100.0	126	100.0	247	100.0		
Specified.............	36	100.0	85	98.8	126	93.3	247	96.1		
Unspecified...........	0	.0	1	1.2	9	6.7	10	3.9		
Total..............	36	100.0	86	100.0	135	100.0	257	100.0		
χ^2:										
Specified..........	6.00NS		16.01**		150.19**					
Without combustible liquids....	ND		ND		24.36*					

ND Not determined.
*Significant at 5-pct level. **Significant at 1-pct level.
[1]In many fires, more than 1 substance was burning.

liquids fires definitely increased across time periods, while that of timber decreased.

Location

The locations of fires in surface metal and nonmetal mines appear in table 33. For the first two time periods, the overwhelming majority of fires occurred in the surface building location, while for the last period, the split was about 50-50 between the surface building and a surface location other than the building.

Equipment Involved

Table 34 shows surface fires by equipment for the three time periods. As with its counterpart table 12 on underground

TABLE 33. - Reported surface fires by location, three time periods

Location	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Surface building......	16	80.0	44	67.7	54	44.6	114	53.3	1.06	3.00**
Surface...............	0	.0	0	.0	67	55.4	67	32.5	ND	7.50**
Other.................	4	20.0	21	32.3	0	.0	25	12.1	ND	ND
Total specified....	20	100.0	65	100.0	121	100.0	206	100.0		
Specified.............	20	95.2	65	100.0	121	96.0	206	97.2		
Unspecified...........	1	4.8	0	.0	5	4.0	6	2.8		
Total.............	21	100.0	65	100.0	126	100.0	212	100.0		

ND Not determined. **Significant at 1-pct level.

TABLE 34. - Reported surface fires by equipment involved, three time periods

Equipment	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Mobile................	0	0.0	8	22.2	51	63.0	59	44.0	2.11*	4.07**
Conveyor..............	1	5.9	4	11.1	9	11.1	14	10.4	.61	ND
Electrical............	2	11.8	6	16.7	4	4.9	12	9.0	.47	2.09*
Other.................	14	82.4	18	50.0	17	21.0	49	36.6	ND	ND
Total specified....	17	100.0	36	100.0	81	100.0	134	100.0		
Specified.............	17	81.0	36	55.4	81	64.3	134	63.2		
Unspecified-unknown-none[1]................	4	19.0	29	44.6	45	35.7	78	36.8		
Total.............	21	100.0	65	100.0	126	100.0	212	100.0		

ND Not determined.
*Significant at 5-pct level. **Significant at 1-pct level.
[1]The reporting mechanism did not permit the classification of fires into three separate categories.

fires, changes in the reporting mechanism for the "Unspecified," "None," and "Unknown" categories make it impossible to obtain a separate fire count for each category. The combination of these three categories comprises a major portion of the total fires for all the time periods. Where equipment is involved, in recent time periods, more fires were associated with the mobile equipment type.

Means of Detection

Means of fire detection appear in table 35. In the most recent time period, the means of detection was not specified for a large portion (21.4 pct) of the fires, thus raising some questions as to the completeness of the data. Of the specified means of detection, almost all were operators and/or workers. The relative frequency of fires discovered immediately increased while that of fires not immediately discovered decreased. This is further substantiated by the next table, which classifies fires by duration. Hence, either operators and workers were becoming incresingly aware of fires and discovering them at an early stage, or for some reason there were more fires under 30 min being reported in the most recent time period.

Duration

Duration of surface fires appears in table 36. Duration is not specified for a large portion of fires for all the periods; the analysis of this table is thus limited to those fires where the duration is specified. As there were too few specified fires in the period 1950-67, a

TABLE 35. - Reported surface fires by means of detection, three time periods

Means of detection	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Operator-worker (immediate)..........	7	36.8	29	46.8	84	84.8	120	66.7	0.76	5.14^{**}
Workers (not immediate)...........	8	42.1	26	41.9	12	12.1	46	25.6	ND	4.33^{**}
Other.................	4	21.1	7	11.3	3	3.0	14	7.8	ND	ND
Total specified....	19	100.0	62	100.0	99	100.0	180	100.0		
Specified.............	19	90.5	62	95.4	99	78.6	180	84.9		
Unspecified...........	2	9.5	3	4.6	27	21.4	32	15.1		
Total.............	21	100.0	65	100.0	126	100.0	212	100.0		

ND Not determined. **Significant at 1-pct level.

TABLE 36. - Reported surface fires by duration, three time periods

Duration, h	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
0 to 0.5..............	3	27.3	16	41.0	29	59.2	48	48.5	0.83	1.69^{*}
0.5 to 1..............	1	9.1	10	25.6	10	20.4	21	21.2	1.17	.58
1+ to 4...............	3	27.3	8	20.5	6	12.2	17	17.2	.84	1.05
4+ to 24..............	4	36.4	2	5.1	2	4.1	8	8.1	2.81^{**}	ND
24+...................	0	.0	3	7.7	2	4.1	5	5.1	.95	.73
Total specified....	11	100.0	39	100.0	49	100.0	99	100.0		
Specified............	11	52.4	39	60.0	49	38.9	99	46.7		
Unspecified..........	10	47.6	26	40.0	77	61.1	113	53.3		
Total.............	21	100.0	65	100.0	126	100.0	212	100.0		
χ^2: Specified........	ND		16.51^{**}		51.51^{**}					

ND Not determined. *Significant at 5-pct level. **Significant at 1-pct level.

chi-square test was not performed. For the remaining two time periods, the number of fires is not evenly distributed across the fire duration categories. As mentioned previously, the relative frequency of fires under 30 min has increased in recent times. Also, the proportion of fires was significantly down in the 4- to 24-h category between 1950-67 and 1968-77.

Number of Injuries

Table 37 shows surface fires by number of injuries for the three time periods. In the first two time periods, approximately 85 pct of the fires involved no injuries, whereas in the most recent time period, this was true for only about 45 pct of the cases. In recent times there has definitely been a substantial increase in the proportion of fires being reported with one injury. This means either more workers have been sustaining fire injuries or changes in law and/or attitude have occurred that are affecting the reporting; that is, injuries that were previously not reported were being reported in the most recent time period.

Number of Deaths

Table 38 contains fires by number of deaths. The only significant result, fortunately, is the overall reporting frequency of nonfatal fires. Once the nonfatal fires are removed, the only remaining category is fires involving one death.

TABLE 37. - Reported surface fires by number of injuries, three time periods

Number of injuries	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
0	18	85.7	54	83.1	56	44.4	128	60.4	ND	5.12**
1	2	9.5	7	10.8	65	51.6	74	34.9	ND	5.51**
2 to 5	0	.0	4	6.2	4	3.2	8	3.8	ND	ND
6 to 10	1	4.8	0	.0	1	.8	2	.9	ND	ND
10+	0	.0	0	.0	0	.0	0	.0	ND	ND
Total	21	100.0	65	100.0	126	100.0	212	100.0	NAp	NAp

NAp Not applicable. ND Not determined. **Significant at 1-pct level.

TABLE 38. - Reported surface fires by number of deaths, three time periods

Number of deaths	1950-67		1968-77		1978-84		Total	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct
0	18	85.7	59	90.8	123	97.6	200	94.3
1	3	14.3	6	9.2	3	2.4	12	5.7
2+	0	.0	0	.0	0	.0	0	.0
Total	21	100.0	65	100.0	126	100.0	212	100.0

TABLE 39. - Reported surface fires by successful extinguishing agent,[1] three time periods

Extinguishing agent	Period I 1950-67		Period II 1968-77		Period III 1978-84		Total		t	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	I vs. II	II vs. III
Water	10	45.5	29	49.2	14	50.0	53	48.6	ND	ND
Burned out	9	40.9	11	18.6	4	14.3	24	22.0	2.07*	ND
Dry chemical	1	4.5	10	16.9	6	21.4	17	15.6	1.45	0.50
Other	2	9.1	9	15.3	4	14.3	15	13.8	ND	ND
Total specified	22	100.0	59	100.0	28	100.0	109	100.0		
Specified	22	91.7	59	84.3	28	21.9	109	49.1		
Unspecified	2	8.3	11	15.7	100	78.1	113	50.9		
Total[1]	24	100.0	70	100.0	128	100.0	222	100.0		
Total fires	21	NAp	65	NAp	126	NAp	212	NAp		
χ^2: Specified	11.82**		18.49**		9.71*					

ND Not determined.
*Significant at 5-pct level. **Significant at 1-pct level.
[1]More than 1 successful extinguishing agent used in some fires.

Successful Extinguishing Agent

Table 39 gives the frequency with which an extinguishing agent was successfully used in each of the three time periods. The fires in which two agents were successfully used were entered under both categories in this table. In period 1978-84, the successful extinguishing agent was not specified in about 80 pct (100/126) of the reported fires. Of the specified fires, there were only three, five, and two fires, respectively, in periods I, II, and III that used two extinguishing agents successfully. Since these members are relatively small, this table is not analyzed in the same manner as its counterpart table 23 on

underground fires. Instead, the standard tests were performed. The data show water to be consistently successful in about 50 pct of the specified fires for all three periods. The burned-out method has been used less frequently since 1968.

COMPARISON OF UNDERGROUND AND SURFACE FIRES

Time Trends

Although the total number of fire incidents was approximately the same for underground and surface, the distribution of these incidents across the three time periods was more variable for surface than for underground (fig. 2). The average number of surface fires per year for which a report could be located ranged from 1.2 in 1950-67 to 18.0 in 1978-84. For underground fires the range was from 3.4 to 10.9. Figure 2 also shows that for the most recent time period there were, on the average, 18.0 surface fires reported per year versus 10.9 for underground. Hence, it would appear that in the recent time period the surface area is more hazardous than the underground area. However, this is not the case, as can be seen from figure 3. This is because many more hours were worked in the surface area than in the underground area. Figure 3 also shows 1978 to be the most hazardous year.

Ore Type

Of the major ore types, copper and iron were the only ones involved in both underground fires and surface fires. Over the entire period, copper was the principal ore involved in underground fires and was third in surface fires. Of the specified ore types, copper accounted for about 18.0 pct of the underground fires and 8.6 pct of the surface fires (tables 5 and 29). In terms of incidence rates for the 1978-84 period, it ranks low for both underground and surface fires (figures 4 and 6).

Ignition Source

Electrical equipment was the leading ignition source of undergropund fires. For surface fires, engine heat was the leading ignition source, followed by electrical equipment (tables 7 and 31). For both underground and surface, the proportion of electrical fires decreased while the proportion of engine heat fires increased between 1968-77 and 1978-84.

Burning Substance

As indicated in tables 8 and 32, more than one substance was burning in many fires. Combustible liquids were the predominant burning substance for both underground and surface fires in the period 1978-84. Also, the relative frequency of fires involving combustible liquids increased from one period to the next for both underground and surface fires. The proportion of fires involving timber, on the other hand, dropped sharply between 1950-67 and 1968-77.

Location

Since the major categories for location (tables 9 and 33) differ vastly for underground and surface fires, they are not compared.

Equipment Involved

The predominant equipment involved in both underground and surface fires was of the mobile type. Figure 7 shows a comparison of mobile equipment fires in surface and underground mines over the three time periods. The relative frequency of fires involving this equipment type increased from one period to the next for both surface and underground fires.

Means of Detection

Most fires incidents were detected by the operators and/or workers, both in

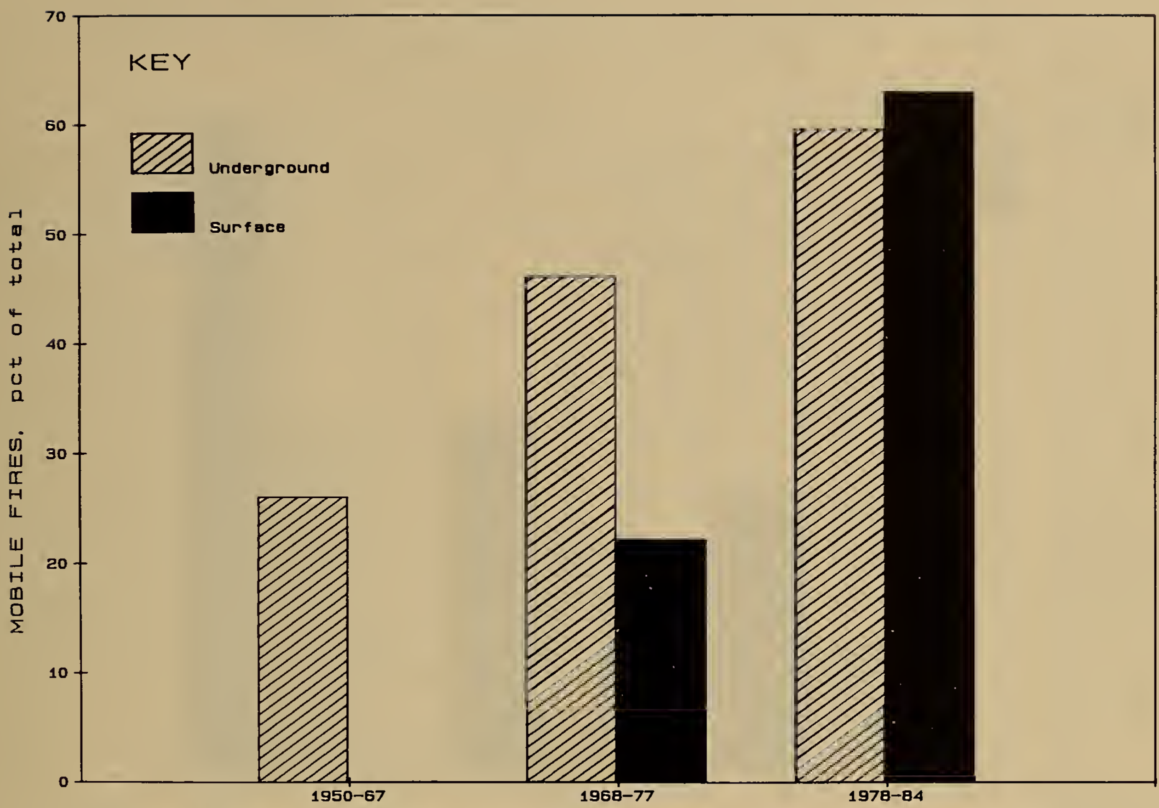

Figure 7.—Percentage of mobile equipment fires, underground versus surface, during three time periods.

surface and underground. Also, data in tables 14 and 35 show that, on the whole, the proportion of fires discovered immediately increased with each time period (fig. 8).

Duration

For the period 1950-67, about 55 pct of the reported underground fires lasted longer than 24 h. There were no surface fires reported in this category for the same period (tables 15 and 36). The percentage of underground fires reported in the 0- to 0.5-h category was approximately the same across the three time periods, while for surface fires there was definitely an increase between 1968-77 and 1978-84.

Number of Injuries

As indicated by tables 17 and 37, the majority of underground and surface fires did not cause injuries. However, for the most recent time period, this was not true in the case of surface fires. In this case, only 44 pct of the fires had no injuries, 52 pct had one injury, and 4 pct had two or more injuries. Also, for both underground and surface, there were no fires resulting in 10 or more injuries.

Number of Deaths

Both in underground and surface, approximately 95 pct of the fires were nonfatal (tables 21 and 38).

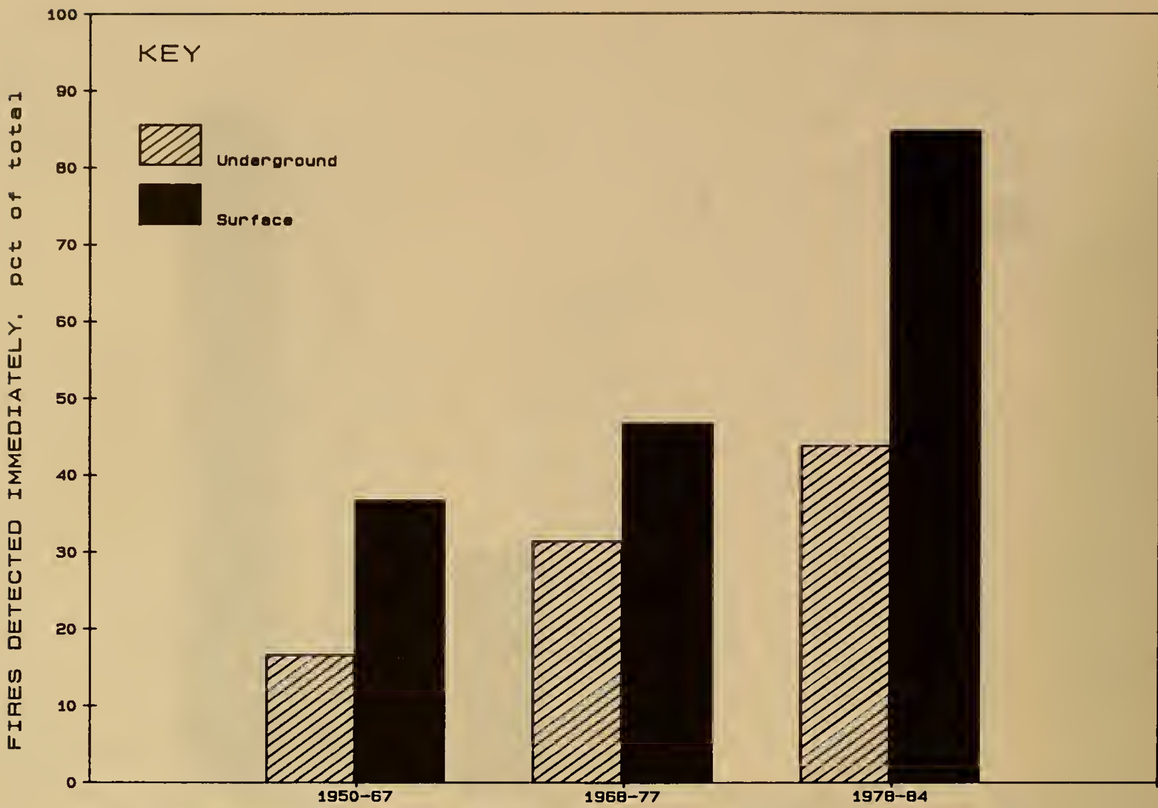

Figure 8.—Percentage of fires detected immediately, underground versus surface, during three time periods.

Successful Extinguishing Agent

As can be seen in tables 23 and 39, water was the predominant successful agent used to extinguish both underground and surface fires. Also, in both underground and surface fires, two extinguishing agents were successfully used in some of the fires.

NONREPORTABLE FIRES

Since 1968, MSHA regulations have required that fires lasting 1/2 h or more or involving an injury must be reported. Each reported fire is investigated by an MSHA inspector who then prepares a fire report. Noninjury fires under 1/2-h duration are not reportable.

To develop a data base that represented mine fires in general, 16 local and regional safety directors in charge of 12 surface mines and 12 underground mines were interviewed to obtain descriptions of nonreportable fires at their mines over the last 5 yr. Internal company memos on these fires were also provided.

Nonreportable data were analyzed in two sets: under the headings of underground fires and surface fires. A total of 20 underground (table 40) and 22 surface (table 41) fire reports were obtained.

TABLE 40. - Nonreportable underground fires

(Based on sample of 20 reports)

	Number		Number
Ignition source:		By location--Con.	
Electrical	10	Working face	1
Welding	4	Other	1
Friction	3	Unspecified	4
Engine heat	1	By equipment involved:	
Spontaneous combustion	1	Mobile	8
Unspecified	1	Electrical	3
By burning substance:[1]		Maintenance-shop	3
Combustible liquids	8	None	5
Wiring insulation	7	Unspecified-unknown	1
Timber	7	By successful extinguishing agent:[2]	
Rubber hose	1	Dry chemical	15
By location:		Cut off electrical power	5
Haulageway-drift	9	Water	4
Substation	3	Seals	1
Shaft	1	Other	2
Mined-out area	1		

[1]More than 1 burning substance involved in some fires.
[2]More than 1 successful extinguishing agent used in some fires.

TABLE 41. - Nonreportable surface fires

(Based on sample of 22 reports)

	Number		Number
Ignition source:		By equipment involved:	
Welding	5	Mobile	14
Electrical	4	Conveyor	2
Engine heat	3	Electrical	1
Friction	2	None	1
Other	2	Unspecified	4
Unspecified	6	By successful extinguishing agent:[2]	
By burning substance:[1]		Dry chemical	13
Combustible liquids	12	Water	1
Insulation	3	Burned out	1
Rubber	2	Other	5
Other	4	Unspecified	3
Unspecified	2		
By location:			
Surface	14		
Surface building	5		
Unspecified	3		

[1]More than 1 burning substance involved in some fires.
[2]More than 1 successful extinguishing agent used in some fires.

UNDERGROUND FIRES

Ignition Source

Most of the nonreportable underground fires were electrical in origin, primarily from wiring shorts. The second highest ignition sources were welding sparks or hot slag and friction, primarily from welding near combustibles and overheating brakes, respectively.

Burning Substance

Combustible liquids, wiring insulation, and timber were nearly equal in frequency of involvement.

Location

As with reported fires, the most frequent location of nonreportable fires was along haulageways and in drift entries where activity is high. Nonreportable fires also occurred with a relative high frequency at substations or switchboxes.

Equipment Involved

Unlike the reported fires, it was possible to separate the fires which involved no equipment from those that were unspecified or unknown. Fires where no equipment was involved usually resulted from welding or cutting, where combustibles such as timber or grease and oil were ignited. Where equipment was involved, the most frequent type was mobile, as was the case with reported fires.

Successful Extinguishing Agent

Unlike the reported fires, the most frequently used agent here was one or more hand-portable dry chemical extinguishers. Also, water and the local removal of electric power were used with relative frequency.

SURFACE FIRES

Ignition Source

Welding, electrical, and engine heat were frequently cited as ignition sources. Welding sparks can ignite grease or oil that has accumulated on vehicles. Electrical fires are generally from wiring shorts that ignite diesel fuel or hydraulic fluid. Engine heat can ignite hydraulic fluid or diesel fuel from a ruptured line.

Burning Substances

As with reported fires, combustible liquids were most frequently involved.

Location

Most surface fires occurred along haulage roads or in the pit area on mobile machinery.

Equipment Involved

An overwhelming majority of nonreportable surface fires involved mobile machinery such as haulage trucks, front-end loaders, and flatbed welding trucks. These findings are consistent with those from fires that were reported.

Successful Extinguishing Agent

Most of these fires were extinguished by hand-portable dry chemical extinguishers and one automatic fire suppression system. This finding is quite different from that for reported fires where water is consistently the most successful extinguishing agent used.

OPINION DATA FROM MINE SAFETY DIRECTORS

When gathering data on rare events such as fires, it is often advisable to ask knowledgeable individuals to give hazard opinion data. Consequently, after the mine safety directors related their nonreportable fire data, they were asked to rank various ignition sources, burning substances, successful extinguishing

agents, and equipment on their relative frequencies of occurrence in nonreportable fires. Because of the size of the opinion data sample, it is difficult to specify with any certainty the reliability. These data are presented as a sample of the metal and nonmetal fire experience of the group of mine safety personnel.

UNDERGROUND MINE FIRES

Table 42 contains ranked opinions of ignition sources, burning substances, and successful extinguishing agents for underground nonreportable fires. Each item is listed according to the average rank assigned to it by the safety directors interviewed. The top three ignition sources were welding sparks or hot slag, electrical arcing, and friction. The top two burning substances were combustible liquids and insulation. The top two successful extinguishing agents were dry chemicals and water.

SURFACE MINE FIRES

Table 43 contains ignition sources, burning substances, and successful extinguishing agents for surface nonreportable fires. Each item is listed according to the average rank assigned to it by the safety directors interviewed. The top three ignition sources were welding sparks or slag, engine heat, and electrical arcing. The top two burning substances were combustible liquids and rubber. The top two successful extinguishing agents again were dry chemicals and water.

SUMMARY OF OPINION DATA

After the safety directors were interviewed concerning nonreportable fires, a consensus of general opinions became apparent. The primary causes of nonreportable underground fires were poor maintenance of electrical equipment and poor housekeeping, coupled with a lack of

TABLE 42. - Average rankings of opinion data for ignition source, burning substance, and successful extinguishing agent, underground fires

Rank	Ignition source	Rank	Burning substance	Rank	Extinguishing agent
1...	Welding sparks or slag.	1...	Combustible liquids.	1...	Dry chemical.
2...	Electrical.	2...	Wiring insulation.	2...	Water.
3...	Friction.	3...	Rubber (hose or belt).	3...	Other.
4...	Engine heat.	4...	Timber, lagging, etc.		
5...	Spontaneous combustion.	5...	Other.		
6...	Other.				

TABLE 43. - Average rankings of opinion data for ignition source, burning substance, and successful extinguishing agent, surface fires

Rank	Ignition source	Rank	Burning substance	Rank	Extinguishing agent
1...	Welding sparks or slag.	1...	Combustible liquids.	1...	Dry chemical.
2...	Engine heat.	2...	Rubber (hose or belt).	2...	Water.
3...	Electrical.	3...	Insulation.	3...	Other.
4...	Spontaneous combustion.	4...	Other.		
5...	Other.	5...	Timber, lagging, etc.		

caution on the part of welders when working near combustibles. Welding on underground mining machinery frequently involves the spot ignition of combustibles that accumulate on this equipment. The primary causes of nonreportable surface fires were poor equipment design, poor maintenance, and poor housekeeping. The routing of fluid lines on surface mining equipment was frequently cited as contributing to an increased fire hazard. Several safety directors mentioned efforts undertaken at their mines to reroute or shield these lines from the ignition sources of electrical arcing and engine heat. Leaks of hydraulic fluid, oil, and other lubricants frequently collect in hard-to-reach locations. These substances eventually are ignited by a cutting torch, electrical arc, or engine heat.

SUMMARY

Major findings of the study appear in tables 44 and 45. The most frequent ignition sources, burning substances, eqiupment types, locations, and successful extinguishing agents of reported and nonreportable fires are discussed below.

IGNITION SOURCE

The majority of underground mine fires, both reported and nonreportable, were electrical. Electrical equipment was also the primary cause of underground fires resulting in injuries during the period 1950-84. In recent times, however, engine heat has become the leading cause of fires resulting in injuries. Engine heat was the leading ignition source for reported surface fires, and welding for nonreportable surface fires.

TABLE 44. - Major study findings of reported fires

(Factors listed in sequence of significance)

Category	1950-77	1978-84	Total
UNDERGROUND			
Ignition source..	Electrical, welding..	Electrical, engine heat.	Electrical, welding, engine heat.
Burning substance	Timber, insulation, combustible liquids.	Combustible liquids, timber, insulation.	Timber, combustible liquids, insulation.
Location.........	Haulageway-drift, shaft-raise-winze.	Haulageway-drift, shaft-raise-winze.	Haulageway-drift, shaft-raise-winze.
Equipment involved.	Mobile, electrical..	Mobile, electrical..	Mobile, electrical.
Successful extinguishing agent.	Water, dry chemical.	Water, dry chemical.	Water, dry chemical.
SURFACE			
Ignition source..	Electrical, welding, engine heat.	Engine heat, welding, electrical.	Engine heat, electrical, welding.
Burning substance	Combustible liquids, construction material.	Combustible liquids, construction material.	Combustible liquids, Construction materials.
Location.........	Surface building.....	Surface, surface building.	Surface building, surface.
Equipment involved.	Mobile, electrical...	Mobile, conveyor....	Mobile, conveyor, electrical.
Successful extinguishing agent.	Water, burned out....	Water, dry chemical.	Water, burned out.

TABLE 45. - Major study findings of nonreportable fires

(Factors listed in sequence of significance)

Category	Underground	Surface
NONREPORTABLE FIRES		
Ignition source.........	Electrical, welding, friction.......	Welding, electrical, engine heat.
Burning substance.......	Combustible liquids, wiring insulation, timber.	Combustibles liquids, insulation.
Location................	Haulageway-drift, substation........	Surface, surface building.
Equipment involved......	Mobile, electrical, maintenance-shop	Mobile.
Successful extinguishing agent.	Dry chemical, cut off electrical power, water.	Dry chemical.
OPINION DATA		
Ignition source.........	Welding, electrical.................	Welding, engine heat.
Burning substance.......	Combustible liquids, wiring insulation.	Combustible liquids, rubber (hose or belt).
Successful extinguishing agent.	Dry chemical, water.................	Dry chemical, water.

BURNING SUBSTANCE

The most frequent burning substance in reported underground fires was timber, followed by combustible liquids and insulation. In nonreportable underground fires, combustible liquids, wiring insulation, and timber were involved with about equal frequency. For reported surface fires, the most frequent burning substance was combustible liquids, followed by construction material. In nonreportable surface fires, combustible liquids were most frequently involved.

LOCATION

Reported underground fires occurred along haulageways or in drift entries where electrical and diesel equipment are concentrated. Nonreportable fires also occurred at these locations more frequently than at any other.

Reported surface fires occurred primarily in mill buildings, and nonreportable surface fires occurred primarily on mobile equipment along haulage roads or in the pit area. In recent times, however, the reported surface fire locations were about evenly split between surface building and surface area other than building.

EQUIPMENT INVOLVED

The equipment most frequently involved in reported and nonreportable underground and surface fires is the mobile type such as load-haul-dumps. These vehicle fires are more quickly detected and are extinguished with hand-portable extinguishers since there is less structure to collect smoke or otherwise conceal the fire.

SUCCESSFUL EXTINGUISHING AGENT

The most frequently successful extinguishing agent for reported fires was water. For nonreportable fires, dry chemical hand-portable fire extinguishers were used most often. This is consistent with the duration of reportable fires. The first attack on a fire is generally with a hand-portable extinguisher. If the attempt is successful, then the fire is most likely extinguished at the nonreportable stage. If the fire has grown in size, or initial extinguishing attempts prove unsuccessful, then the fire will probably become reportable while water is brought to the area and applied to the fire.

CONCLUSIONS

Fire incidence rates in both surface and underground mines are not declining. Despite the considerable efforts of mine safety personnel, regulatory action, and fire safety-related research, little progress toward reducing the incidence of fire in recent years (1978-84) is apparent. One possible explanation, which is supported to some extent by the data on ignition sources, burning substances, and equipment involved, is that fire hazards are changing as mining methods, materials, and equipment evolve. As specific fire hazards are recognized and corrected, new mining technology introduces other hazards into the workplace. This explanation suggests that the present level of fire safety effort may not succeed in reducing fire incidence rates, and that an accelerated pace of activity with particular focus on newly emerging mining technologies is required if incidence rates are to be reduced.

Conclusions regarding the relative importance of a given fire hazard for one time period do not necessarily hold for subsequent periods, suggesting the value of regular updates to the fire incident data base. Timely collection, analysis, and publication of such data will help ensure that fire safety efforts will address the greatest needs.

Finally, the depth and breadth of the data contained in this report is significant in itself. The level of detail provided will enable users to concentrate their efforts on the research instead of on collecting data, thereby maximizing effectiveness. The relative hazardousness of various equipment and procedures has been presented in clear and concise fashion. The data were put on a floppy disk in the Lotus 1-2-3 format to facilitate the analysis. Microdata are also available from the authors on hard copy.

APPENDIX

MSHA fire reports for 1950 through 1977 were acquired from the following MSHA inspection offices:

<u>Northeastern District</u>

Northeastern District Office
Pittsburgh, PA 15213

Pittsburgh Subdistrict Office
Pittsburgh, PA 15213

Albany Subdistrict Office
Albany, NY 12201

<u>Southeastern District</u>

Southeastern District Office
Birmingham, AL 35209

Birmingham Subdistrict Office
Birmingham, AL 35209

Knoxville Subdistrict Office
Knoxville, TN 37902

<u>North Central District</u>

North Central District Office
Duluth, MN 55802

Duluth Subdistrict Office
Duluth, MN 55802

Vincennes Subdistrict Office
Vincennes, IN 47591

<u>South Central District</u>

South Central District Office
Dallas, TX 75209

Dallas Subdistrict Office
Dallas, TX 75209

Rolla Subdistrict Office
Rolla, MO 65401

<u>Rocky Mountain District</u>

Rocky Mountain District Office
Denver, CO 80225

Denver Subdistrict Office
Denver, CO 80225

Salt Lake City Subdistrict Office
Salt Lake City, UT 84115

<u>Western District</u>

Western District Office
Alameda, CA 94501

Bellevue Subdistrict Office
Bellevue, WA 98004

Phoenix Subdistrict Office
Phoenix, AZ 85004

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